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DESIGN PARAMETERS FOR ANIMAL WASTE TREATMENT SYSTEMS

T. B. S. Prakasam, et al

New York State College of Agriculture and
Life Sciences

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16. Abstract

Laboratory, pilot plant, and full-scale studies evaluated design parameters for liquid aeration systems treating livestock waste. Of the various approaches tested, the mass balance approach is the preferred approach since it yielded results comparable to other approaches and involved fewer assumptions. Equations were developed to predict the COD and suspended solids concentrations in the effluent from the aeration systems. A design example is included for both odor control and stabilization of the waste including minimal aeration as well as nitrification.

In laboratory and full-scale livestock waste treatment systems uncontrolled nitrogen losses occurred. Preliminary investigations identified the engineering opportunities for the control of nitrogen in aeration units by either conservation or removal.

Acid soils conserved nitrogen in poultry manure. Neutral soils accumulated NO_2^- at toxic levels. Untreated manure was inferior to treated manure as a N source. Rates over 30 tons damaged corn. Runoff losses of N and P were slight. Orchard grass responded but bromegrass did not respond to poultry manure applications.

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July 1974

DESIGN PARAMETERS FOR ANIMAL WASTE TREATMENT SYSTEMS

by

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ABSTRACT

Laboratory, pilot plant, and full-scale studies evaluated design parameters for liquid aeration systems treating livestock waste. The evaluations were conducted using a mass balance approach and equations developed by previous investigators. The mass balance approach is the preferred approach since it yielded results comparable to other approaches and involved fewer assumptions. Equations were developed to predict the COD and suspended solids concentrations in the effluent from the aeration systems. A design example is included for both odor control and stabilization of the waste including minimal aeration as well as nitrification.

In laboratory and full-scale livestock waste treatment systems uncontrolled nitrogen losses occurred. Preliminary investigations identified the engineering opportunities for the control of nitrogen in aeration units by either conservation or removal.

Greenhouse corn studies indicated acid soils were more efficient in retaining poultry manure nitrogen than neutral soils. Neutral soils developed toxic NO_2 from poultry manure. There were minor yield differences from several types of treated poultry manure. Untreated manure was an inferior source of N. Rates of poultry manure over 30 tons per hectare damaged corn.

Runoff losses of nitrogen and phosphorus were slight. Orchard grass responded to poultry manure applications but Bromegrass did not.

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SECTION I

CONCLUSIONS

AEROBIC TREATMENT OF ANIMAL WASTES

1. Several approaches were investigated to determine appropriate predictive equations for the concentration of suspended solids and COD in the effluent of a liquid aeration system treating poultry wastewater. The equations developed by a mass balance approach are preferred to the equations developed from those of Monod, Eckenfelder, and McKinney. All of these equations were evaluated in this study for use with animal wastes. The results obtained using the mass balance equations were comparable to results obtained by the other equations. The mass balance equations are preferred because fewer basic assumptions had to be made and fewer empirical constants had to be used.

2. Poultry wastewater has a significant non-biodegradable fraction which must be included when deriving parameters for the design of liquid aeration systems.

3. The two mass balance equations developed to predict the total suspended solids and total COD concentration in the overflow from aerated wastewater are:

a) for suspended solids concentrations

$$K' = \frac{X_i - X}{X \cdot t}$$

Where K' = suspended solids removed coefficient
X_i = influent suspended solids concentration (mg/l)
X = effluent suspended solids concentration (mg/l)
t = liquid detention time (days)

b) for COD concentration

$$K = \frac{Si - \overline{S}}{\overline{S} \cdot t}$$

Where K = COD removal coefficient
Si = influent COD concentration (mg/l)
$\overline{S}$ = effluent COD concentration (mg/l)
t = liquid detention time (day)

4. The coefficients for suspended solids and COD removal (K' and K) were found to increase with an increase in loading factors and obeyed the following relationships:

a) $K' = 0.011 + 0.15X'$

b) $K = 0.017 + 0.11X'$

Where X' = the loading factor (gm COD/gm MLVSS)

The value of K' ranged from 0.011 to 0.176 for the range of loading factors evaluated in the study (0 to 1.1). Similarly K was found to have a range of 0.017 to 0.138 for the same range of loading factors. Values for K' and K were not tested beyond this loading range in this study. Application of the above relationships should be made with caution for loading factors above 1.1.

5. The removal rate coefficient at low loading rates essentially represent the endogenous metabolism coefficient of the waste mixed liquor.

6. Substrate removal in the poultry wastewater exhibited phasic removal patterns with different kinetic constants for each phase. First order kinetics were not able to describe the substrate removal patterns with these wastes.

The phasic removal was attributed to the presence of a readily available substrate which was used rapidly followed by the slow utilization of a less readily available particulate and less soluble substrate.

7. Based on this investigation and using the mass balance equations, the following steps can be used to design an oxidation ditch type treatment system for poultry waste and to predict the effluent quality from such systems.

a) Determine the number of birds contributing waste to the oxidation ditch, determine the actual surface area occupied by the cages in the building, and assume that the ditch will be built directly below the cages.

b) Size the surface area of the oxidation ditch to fit the space below the birds so that the waste will drop directly from cages into the ditch.

c) Assume the liquid depth to be between 18 and 24 inches. This will permit calculation of the liquid volume and, assuming a constant liquid and solid input from the birds, will fix the detention time of the ditch. The waste input can be obtained from average data on the waste characteristics for the type of birds in the cages.

d) Assume that a mixed liquor total solids concentration of between 1-2% will be maintained in the oxidation ditch. This will permit maximum oxygen transfer by the rotor. Based on the volume of the ditch contents and concentration of volatile suspended solids, the total weight of volatile suspended solids in the ditch can be obtained.

e) Establish the loading factor by dividing the COD (gm) entering the ditch (COD, gm/bird x number of birds) by the VSS (gms) in the ditch.

f) From the equations given in conclusion 4, obtain K' and K.

g) Using these values of K' and K, the effluent quality can be predicted by using the equation given in conclusion 3.

8. The oxygen requirements for the treatment of poultry waste depend on the objectives of the treatment. A system designed only for odor control and partial stabilization will have a lower oxygen requirement than a system designed for odor control and nitrification. For example, a system designed to treat wastes from 10,000 birds will require about 215 pounds of oxygen/day to achieve odor control and partial stabilization of the wastes. For the type of waste used in the example, an additional 70 pounds of oxygen per day will be required if nitrification of the waste is also desired. A higher amount of O_2 will be needed for nitrification, if the waste under consideration has a higher concentration of TKN than the one considered in the above example.

9. Based on laboratory systems operating under equilibrium conditions, the oxygen uptake rate of mixed liquors increased as the loading rate increased. These uptake rates were between 1-3 mg of oxygen/gm TVS/hr up to a loading rate of 0.13 gm total COD/gm MLVSS/day.

A rotor may be installed to provide aeration of the mixed liquor. The size of the rotor can be calculated by a) computing the oxygen demand of the waste per day in pounds; this depends again on whether nitrification is desired or not, b) computing the oxygen transfer rate for unit length of rotor, and c) determining the required length of rotor. Our laboratory experiments and pilot plant data indicated that approximately 0.5 lbs of oxygen could be transferred per foot of rotor length per hour at a 2 in. immersion depth, using a Thrive Center rotor.

NITROGEN REMOVAL DURING AEROBIC WASTE TREATMENT

1. Batch scale experiments on the nitrification of poultry wastewater suspensions confirmed that nitrogen was lost from the nitrifying mixed liquors by denitrification which occurred under aerobic conditions. At a constant rate of aeration, nitrogen losses from a nitrifying reactor were higher as the loading rate increased. This was a result of increased oxygen demand of the mixed liquor.

2. Observations on a pilot plant scale oxidation ditch and full scale oxidation ditch indicated that they were effective as odor controlling devices. Nitrogen losses also occurred in the systems and could be traced to either ammonia volatilization or denitrification of the nitrate and nitrate formed during treatment. During the start-up phase of the operation of the oxidation ditch systems, a loss of as much as 70% of the input nitrogen could be attributed to ammonia volatilization.

3. In the pilot plant oxidation ditch, as nitrification occurred, the nitrogen losses due to ammonia volatilization became negligible. When the system was operated on a flow through mode, about 30% of the nitrogen was lost and could be attributed to the denitrification of the nitrified mixed liquor. When denitrification was induced deliberately by stopping the rotor and mixing was provided intermittently by turning the rotor on, almost all the NO_3^- and NO_2^- was denitrified. During a six month operation of the ditch, denitrification was carried out deliberately for a short time after the first three months of operation. The losses of NO_3-N due to this denitrification were only 8% during this short period as compared to the 23% loss due to uncontrolled denitrification that took place over a much longer period as the ditch operated under aerobic conditions. It appears that controlled denitrification losses may be increased by employing a frequent repetitive

nitrification-denitrification scheme. This will facilitate a higher removal of oxidized nitrogen.

4. Studies with the full scale oxidation ditch at the Houghton Poultry Farm revealed that perceptible nitrification could not be achieved due to low dissolved oxygen concentration in the mixed liquor. The dissolved oxygen concentration was less than 1 mg/l during 64% of the time and in 70% of the ditch volume. The loss of nitrogen due to ammonia volatilization amounted to about 40% of the total nitrogen input. When aeration of the mixed liquor is not adequate, there is the risk of ammonia odors, particularly when the ventilation in the building is poor. A practical solution to eliminate the ammonia odor is to design the system for achieving nitrification as described in the section on aerobic treatment.

LAND APPLICATION AND CROP RESPONSE TO TREATED POULTRY MANURE

Research activities were equally divided between greenhouse and field studies.

From the greenhouse studies it was concluded that:

1. Acid soils in the Northeast and North Central U.S.A. have a greater potential for fixing the nitrogen liberated from poultry manure than do neutral soils. Soil analysis of greenhouse samples show that nitrogen from poultry manure, under acid conditions, tends to be held in the soil as ammonium ions. In the case of neutral soils this ammonium nitrogen tends to be oxidized to nitrates. The nitrate form is then more easily leached from the soil.

2. It was also established that soils at a pH of 7-8 tended to accumulate NO_2^- ions which were toxic to the test corn plants. This was especially true for oxidation ditch treated manure and raw manure.

3. There was no consistently superior corn yield response from one or the other kind of treated poultry manure application. At lower rates (about 200 kg/ha) raw manure was generally as good as treated manure. At higher rates raw manure was a relatively poorer source of nitrogen. Diffused air treated manure tended to be superior at higher rates of application.

4. Greenhouse production of corn dry matter increased with increased fertilization by poultry manure of all kinds except where the NO_2^- ion caused toxicity to the corn plants.

5. Under "normal" rates of fertilization with poultry manure corn plants could extract only 2/3 of the available nitrogen from greenhouse pots. The higher rates of nitrogen fertilization from manure resulted in a lower rate of nitrogen extraction by the test corn plants.

From the Field studies it was concluded that:

6. The residual benefits of poultry manure applied in 1971 were clearly evident in 1972. Using corn as the test crop these 1971 manured plots yielded 80-90% of similar plots manured both in 1971 and 1972. These preliminary results suggest alternate years might be used for fertilizing corn with poultry manure.

7. A normal crop of corn grown in the field will remove approximately 100 kg/ha of nitrogen from the soil. Usually the soil will supply 50 kg/ha of nitrogen. Poultry manure applied at the rate of 100 kg/ha N will supply approximately 50 kg N/ha. It is apparent that excessive rates of poultry manure fertilization should result in surplus nitrogen production. Such a nitrogen surplus either stays in the soil or leaches out into ground water.

8. A series of runoff plot measurements were made for the following parameters: runoff, soluble phosphorus, nitrate, ammonium ions, soil losses, organic matter losses, total sediment phosphorus, total sediment nitrogen. Oxidation ditch poultry manure and raw manure were applied at varying rates. There were no significant differences in losses to the environment.

9. Two grasses, orchard grass and bromegrass, were established and utilized for varying rates of poultry manure fertilization. Oxidation ditch treated manure and raw manure were applied. Bromegrass did not respond to any kind of poultry manure application. Applied in the spring oxidation ditch manure was superior to fresh manure when applied to orchard grass. However, there was no difference in yield of orchard grass from fall applied manure treatments.

10. In a cooperative field trial rates of poultry manure application in excess of 30 metric tons per hectare depressed corn yields. Preliminary evidence suggests that this yield depression may be due to a high content of soluble salts in the poultry manure.

SECTION II

RECOMMENDATIONS

AEROBIC TREATMENT OF ANIMAL WASTES

1. Since the EPA effluent guidelines do not permit the discharge of effluents from livestock operation to surface waters, it is not necessary to design treatment systems to meet the secondary effluent characteristics. The objective in designing treatment systems for these wastes should be only to achieve odor control and a degree of treatment that is compatible with criteria for the ultimate disposal of the effluents on land.

2. Based on the equations developed in this study, liquid aeration systems can be designed for the control of odor and stabilization of livestock wastes. The following approach is suggested for designing an oxidation ditch type of aeration system and predicting the quality of effluent resulting from such a system.

a) Determine the number of birds contributing waste to the treatment system and the actual surface area occupied by the cages in the building. Assume that the oxidation ditch will be built directly below the cages.

b) Determine the surface area of the oxidation ditch to fit the space below the birds so that the waste will drop directly from cage into the ditch.

c) Assume the liquid depth to be between 18 and 24 inches (≈46 and 61 cm). This will permit calculation of the ditch volume, and assuming a constant volume of waste input from the birds, will fix the detention time of the ditch. In actual practice this volume can be obtained from average data on the waste characteristics for the type of birds in the cages.

d) Maintain the mixed liquor total solids concentration between 1-2% to permit maximum oxygen transfer by the rotor.

e) Find the loading factor of the ditch as follows: 1) compute the COD in kg entering the ditch every day, 2) compute the weight of volatile suspended solids (kg) by multiplying the concentration of volatile suspended solids in the ditch by the volume of the ditch contents (mg/l x liters/1000 = kg of volatile suspended solids). The loading factor is COD, (kg)/VSS, (kg).

f) To predict the effluent quality use the following approach: 1) Compute K' and K, the suspended solids and COD removal coefficients respectively, using the following equations:

$$K' = 0.011 + 0.15\ X'$$

$$K = 0.017 + 0.11\ X'$$

where

X' is the loading factor.

2) Using the above computed values for K' and K predict the effluent quality using the following equations:

$$K' = \frac{Xi - x}{x \cdot t}$$

and

$$K = \frac{\bar{S}i - \bar{S}}{\bar{S} \cdot t}$$

where

Xi = influent suspended solids concentration, mg/l
X = effluent suspended solids concentration

S_i = influent COD concentration, mg/l
$\bar{S}$ = effluent COD concentration
t = detention time, days

3. When odor control is the objective, design of the system for minimal aeration is recommended. In this approach just enough oxygen is provided to meet the demand for the oxidation of carbonaceous matter. A residual dissolved oxygen concentration is not needed. However, if the waste needs to be stabilized to the level of ammonia oxidation, the aeration equipment size also should consider the oxygen demand due to nitrification and a residual dissolved oxygen concentration of 2.0 mg/liter of the mixed liquor. For poultry wastes this additional nitrogenous oxygen demand should be established by analyzing the waste for nitrogen content and by assuming that at least 80% of it will be available for nitrification. For designing purposes each kg of nitrifiable TKN may be considered to exert about 4.6 kg of oxygen demand.

NITROGEN REMOVAL DURING AEROBIC WASTE TREATMENT

1. Although it is premature to make any recommendations pertaining to nitrogen control in poultry wastewater, liquid aeration system does seem to provide opportunities for the control of nitrogen in livestock wastes. Detailed pilot plant studies are being conducted and appropriate recommendations will be made from data collected in the final year of the project.

LAND APPLICATION AND CROP RESPONSE TO TREATED POULTRY MANURE

Recognizing the short duration of the research and weather extremes experienced with the field trials, recommendations are based on our limited knowledge to date.

1. Poultry manure that has been aerobically treated for odor control can be used for crop growth, and is an excellent source of plant nutrients.

2. Higher rates of poultry manure can be applied to acid soils ($pH \leq 5.0$) in contrast to those rates applied to slightly acid to neutral soils. For maximum yields, it is recommended that application rates for corn not exceed 224 kg N/ha (200 lbs N/acre) of aerobically treated manure on soils with a pH of 5.0 or greater and 448 kg N/ha (400 lbs N/acre) on acid soils ($pH<5.0$). Raw manure containing 50% moisture and 1% nitrogen (wet weight basis) can be applied to soils at one-half the recommended rate for treated manure.

3. Application rates for perennial forage grasses, from both treated and untreated sources can be applied at the rate of 112 kg N/ha (100 lbs N/acre).

4. Due to residual carryover of nitrogen during the second year, rates approaching 448 kg N/ha (440 lbs N/acre), should be applied only in alternate years to avoid degradation of water quality.

Because of the short duration of the research as well as extreme weather conditions during this period, it is inappropriate at this time to recommend a maximum rate of application for adequate plant growth while maintaining a high degree of water quality. Additional data are currently being collected which will hopefully provide for an accurate estimation of the rate and water quality interaction under a variety of climatological sequences.

SECTION III

PROJECT NEED AND OBJECTIVES

Project Need

Agricultural production is becoming more intensive. Increased efficiency of agricultural production has generated a variety of pollution control problems. Large scale confined animal operations developed in the past decades have resulted in both water and air pollution due to accumulated wastes. These operations have been a source of fish kills, lowered recreational values, and nuisances to surrounding areas. With current animal waste handling methods, odors can be a significant problem, especially during land spreading. Animal wastes can contribute to impaired water quality by heavy organic loads, by excessive nutrients, and by direct discharge to streams. Land disposal of these wastes may result in subsequent runoff and sub-surface percolation of contaminants.

Liquid waste handling and treatment systems have developed because of the desire to reduce labor and maintenance costs. These systems also provide a better environment for the animals and workers within the controlled production facilities. Experience has indicated that properly designed and operated aerobic systems can eliminate the odor problems associated with many of the current systems and can reduce the pollution potential of the wastes prior to disposal on the land.

Research on aerobic treatment processes for animal wastes has indicated the extent to which aerobic treatment can be used with specific animal wastes and the general management conditions under which the aerobic processes can function. Only recently has the necessary design information begun to be available for aerobic biological systems to control odors, provide a specific degree of treatment, or to provide a removal of excess nitrogen from animal wastes.

The characteristics of animal wastes range from dilute wastes such as those obtained from duck production operations with characteristics similar to strong sewage to semi-solid wastes and such as those from cattle and poultry wastes which may have moisture contents of 75-85%.

To meet effluent criteria for their discharge to surface waters, extremely high removal efficiencies, 99+%, must be obtained because of the characteristics of the semi-solid animal wastes. In addition, the EPA Effluent Guidelines (1) call for no discharge of animal wastes to surface waters. The high treatment efficiencies and guidelines require close evaluation of combined treatment-land disposal alternatives.

Land has been the traditional site for the disposal and recycle of slurry and semi-solid stored, anaerobic animal wastes. With proper crop and land management, land disposal of animal wastes will remain an economic and acceptable method. Organic and nutrient constituents of these wastes can be incorporated into the soil and removed by crops. Prior treatment to accomplish excessively high BOD, solids, and nutrient removals may not be necessary with disposal on land. Any treatment or stabilization that the wastes receive must be compatible with land and crop management practices including control of excess nutrients that may cause secondary pollution problems.

Aerobic biological treatment systems for animal wastes result in an end product with a) decreased pollutional characteristics because of the treatment, b) different types of available nitrogen, and c) different physical characteristics due to water added and the microbial breakdown of the roughage in the untreated wastes. Only very limited information exists on the rates at which the residue from aerobic animal waste treatment units can be applied to crop and non-cropped land without causing secondary pollution problems. Better information is needed on the best land application methods to dispose of stored untreated animal wastes. Runoff or percolation associated with such land disposal is of prime concern. The fate of the soluble organic and nitrogen forms and the quantities of the treated wastes that can be disposed of under different cropping patterns also needs to be known.

A common approach to waste management problems is to have researchers in various disciplines investigate fundamentals and/or processes. Reports of such research are then made available to the professions. Experience has indicated that while this approach can provide desirable results, a multi-disciplinary approach can provide more meaningful results and conclusions. This project offers the opportunity to integrate research and demonstration activities in the disciplines of sanitary engineering and agronomy. These are key disciplines in agricultural waste management. The sanitary engineer designs the treatment systems to meet specific effluent requirements. The agronomist accepts the treated or untreated wastes and determines the feasible land disposal system. This project permits coordination of these disciplines to demonstrate appropriate design parameters for the treatment and disposal of animal wastes.

Project Objective

The specific objectives of this research are to: a) demonstrate the applicability of sanitary engineering fundamentals to the design of aerobic biological treatment systems for animal wastes, and to develop the necessary design parameters for systems to remove excess nitrogen; b) demonstrate proper management methods for the disposal of animal wastes, including aerobically treated waste, on the land.

The project consists of two parts:

A - Parameters for Aerobic Liquid Waste Treatment Systems

B - Parameters for Land Application of Animal Wastes

Design parameters for combined animal waste treatment-land disposal and parameters for the design of individual waste treatment and individual land disposal methods will be a result of the project. Such a program of research results in design parameters that provide maximum flexibility for those who will use these waste management alternatives.

The emphasis of the project has been to demonstrate, in the field or in large scale systems, the feasible approaches to meet the project objectives. It was necessary, however, to conduct some laboratory and greenhouse studies to: a) clarify the fundamental relationships of the potential processes, especially with wastes of different characteristics, such as land disposal of treated and untreated wastes, and b) to delineate those relationships that appear most feasible for large scale demonstration.

SECTION IV

AEROBIC TREATMENT OF ANIMAL WASTES

INTRODUCTION

The confined production of animals has the potential of contributing to air pollution by odors and dusts generated at the production facilities and to water pollution by the discharge of untreated wastes. Controlled waste treatment processes can reduce or eliminate the air and water pollution potential of animal wastes. Aerobic and anaerobic processes are compatible with these wastes. Aerobic processes are generally preferred in many areas since they can prevent the generation of obnoxious odors and can stabilize the wastes prior to disposal. Examples of possible aerobic processes include oxidation ponds, aerated lagoons, oxidation ditches, activated sludge modifications, and land disposal.

To date (1973), aerobic treatment processes for animal wastes largely have been designed on the basis of previous experiences and situations which produced satisfactory results. Because aerobic treatment processes are biological, an understanding of the processes must be based upon the fundamentals of microbial transformations in the biological waste treatment units. If this understanding can be achieved, rational predictions of performance and better design become possible, and the capabilities of a process can be better utilized. Without an understanding of the funadmentals, the processes can be treated only as "black boxes" in which the performance is subject to parameters seemingly beyond our control. Lack of proper understanding and use of the fundamentals means that successful design and operation of aerobic treatment processes can be based only on prior performance which may be difficult to translate to different wastes and environmental conditions.

The purpose of this study has been to determine and apply the fundamentals of aerobic waste stabilization processes to the treatment of poultry manure. Data were obtained from laboratory, pilot plant, and full-scale aerobic units treating poultry manure. These units were monitored under the direct control of the Agricultural Waste Management Program of the College of Agriculture and Life Sciences, Cornell University. In addition to design parameters developed from the project results, the relationships developed by Monod (2), Eckenfelder (3-6), and McKinney (7-9) were evaluated for their use in the aerobic treatment of these wastes.

The results of the study indicate reasonable approaches for the design of aerobic treatment units for poultry wastes. The general scope of the study included:

- general removal characteristics of the organic material in the wastes
- relationship between microbial growth and available substrate removal
- determination of oxygen demand and rate of consumption
- feasibility of a continuous flow, completely mixed aerobic system
- application of design concepts

BACKGROUND

General

Aerobic biological treatment processes have been utilized for a variety of municipal and industrial wastes. Although the characteristics of animal wastes and wastewaters are different from those of municipal and industrial wastes, established design concepts should be valid if they are modified for the different waste characteristics. The actual application of treatment technology to animal wastes is in its early stages.

To facilitate the application of proper design concepts to the aerobic treatment of animal wastes, established concepts will be reviewed and applied using data obtained in this study. This section will include a review of BOD, COD, and solids removal kinetics, available design approaches, and current processes for the aerobic treatment of animal wastes.

BOD or COD Removal

BOD and COD removal has been investigated in many studies. Zero and higher order reactions have been observed with mixed cultures. Sequential removal patterns have been observed when complex organic wastes were used as a substrate.

BOD removal is related to sludge growth and to the availability and utilization of the substrate contained in the waste. The overall removal rate decreases as the more readily oxidizable components are removed. The total BOD removal can be estimated by a first or second order relationship until the residual BOD becomes small. At and below this residual, the BOD removal will follow a zero order reaction. Discontinuous removal kinetics can be used to describe the relationship between BOD removal rate and concentration of BOD remaining, i.e., first order relationships can be used before substrate becomes limiting and zero order after it is limiting.

There are generally two major descriptions of the dependence of growth rate upon substrate concentration in waste treatment. These are illustrated by the work of Monod (2) and by the studies of Garrett and Sawyer (10). Monod relationships predict that the logarithmic growth rate is a continuous function of substrate concentration up to the concentration of substrate at which growth rate becomes a maximum (Figure 1). The other (10) indicates that for practical purposes the relation between growth rate and the remaining soluble BOD is represented by a discontinuous function. Eckenfelder (4), McKinney (7), and others have used this concept for the design of biological waste treatment systems.

Solids Reduction

Considerable research on solids destruction has been reported, especially for the aerobic digestion of biological sludge. Equally important information on solids destruction can be found in studies of the extended aeration process (11-18). In this process, solids destruction is accomplished concurrently with removal of exogenous carbon sources in the incoming waste due to the low food to microorganism (F/M) ratio maintained in the system.

The rate of solids reduction should be considered as related to both aeration time and organic loading rate rather than being independent of these factors. The kinetics of aerobic stabilization has been described by a first order reaction. Data from both batch and continuous flow completely mixed reactors were able to be expressed in this manner. An inert non-biodegradable residue will result from the degradation of the suspended solids and must be considered in all equations describing solids degradation.

The solids removal rate is temperature dependent. The sludge stabilization rate may be defined as the decrease of volatile solids or equivalent COD per unit time or as the reduction of the biological activity of sludge, i.e., the endogenous respiration rate. The percent reduction of volatile solids is not satisfactory to indicate the stability of sludges from aerobic digesters under continual loading conditions because the sludges may have undergone varying degrees of stabilization prior to entering the aerobic digesters. The specific oxygen uptake rate is one of the more reliable indicators of the stabilized conditions of the aerobically digested sludge. Rates in the range of 0.5 to 1.0 mg O_2/gVSS/hr have been associated with well stabilized sludges.

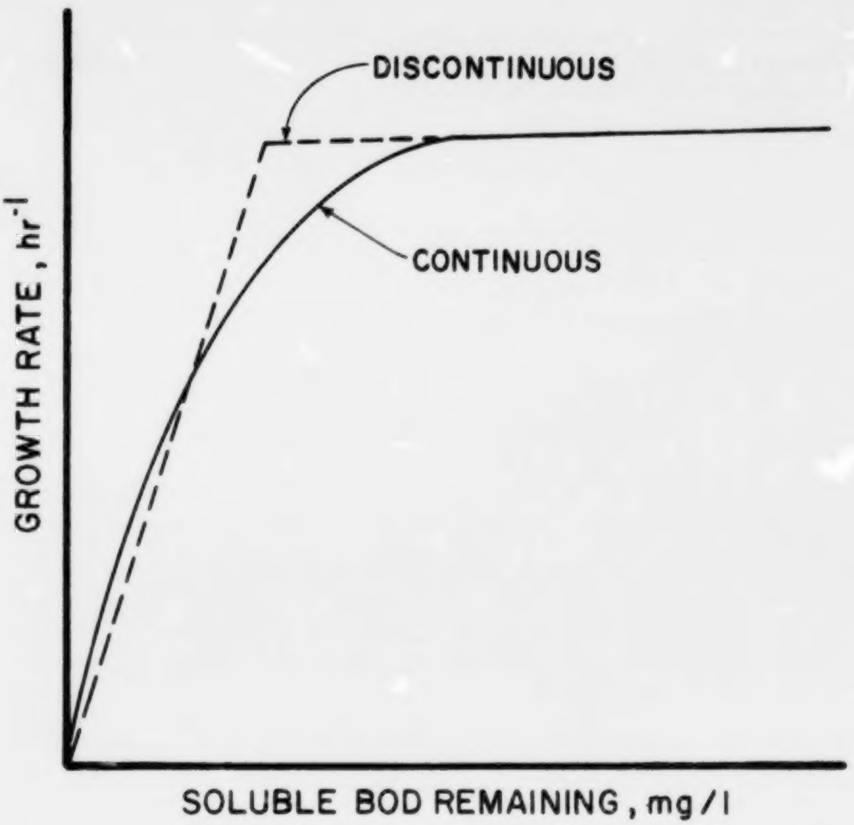


Figure 1. Conceptual relationships between microbial growth rate and microbial substrate (soluble BOD).

PROCESS DESIGN

Three major approaches for the design of aerobic biological treatment processes can be used. These can be illustrated by the use of equations developed by Monod (2), McKinney (7-9), and Eckenfelder (3-6).

Monod

The equation by Monod (2) to describe the relationship between growth rate and concentration of growth limiting nutrient is similar to the Michaelis-Menten equation which described the relationship between substrate and enzyme reactions as follows:

$$\mu = \frac{\mu m S}{Ks + S} \qquad (1)$$

where μ = specific growth rate
μm = maximum value of μ
Ks = saturation constant or the substrate concentration where $\mu = 1/2\mu m$
S = concentration of growth limiting nutrient

The theory and operation of continuous cultures has been reviewed by a number of researchers (19-22) and will be discussed only briefly.

The design of completely mixed continuous flow biological treatment processes normally is based on the premise that a steady state equilibrium can be maintained between the rate at which the substrate is removed or metabolized and the rate of the growth of bacteria. The logarithmic growth rate can be expressed as:

$$\frac{dx}{dt} = \mu x \qquad (2)$$

where x is the concentration of bacterial cells. The relationship, which expresses the net change in microbial cell mass is equal to the amount of microbial cells synthesized from the substrate less the microbial decay:

$$\frac{dx}{dt} = Y\left(\frac{dS}{dt}\right) - bx \tag{3}$$

where Y is the yield coefficent and b is the endogenous coefficient.

When the steady state conditions are established in a once-through, completely mixed, continuous flow system, the rate of change in cell concentration will be zero, i.e.,

$$\frac{dx}{dt} = \mu x - Dx = 0 \tag{4}$$

$$\mu = D = \mu m\left(\frac{S}{Ks + S}\right) \tag{5}$$

D is the dilution rate and equal to the flow rate divided by the volume of the reactor. S is the concentration of substrate in the reactor and therefore in the effluent for a completely mixed once-through system. Therefore, the specific growth rate is related only to the hydraulic control of the reactor. Rearranging Equation (5) results in:

$$S = \frac{Ks \cdot D}{\mu m - D} \tag{6}$$

The change of the substrate concentration can be written into the mass balance:

$$\frac{dS}{dt} = D \cdot Si - D \cdot S - \mu\left(\frac{x}{Y}\right) = 0 \tag{7}$$

Si is the influent substrate concentration. By rearranging equation 7, one obtains

$$x = Y(Si - S) \tag{8}$$

Equations 6 and 8 can be used to calculate the steady state concentrations of biological solids and substrate for any dilution rate if the growth parameters, μm, Ks, and Y are available and were evaluated accurately.

In the evaluation of μ, the substrate concentration in Equation 1 has been expressed as the initial substrate concentration in a batch reactor (So) or the steady state substrate concentration (S) in a completely mixed continuous flow reactor (2). Thus, μm and Ks can be evaluated by either batch or completely mixed continuous flow reactor data. The evaluation of these two parameters for the aerobic treatment of poultry waste will be presented in the results section.

Knowledge of the yield coefficient is important in Equations 3 and 8. The yield coefficient is not necessarily a true constant either for a pure or a heterogeneous microbial population (23-25). As an example, the cell yield from heterogeneous microbial populations of sewage origin which were acclimated to glucose, ranged from 36 to 88% in batch culture, and 32 to 69% in continuous culture (26). The variability in cell yield was explained as due to the ecological variation inherent in a heterogeneous population. A range rather than a single yield constant may be more appropriate in the design and operation of biological waste treatment systems. Such is likely to be the case for the treatment of animal wastes.

Modifications of the Monod equations have been suggested. Chiu et al. (27) (28) indicated that an endogenous respiration term must be added to the Monod model, and the growth parameter must be obtained from low and high dilution rates. The logic was that these values will exhibit a reasonable range of values rather than a single value. Grady et al. (29) concluded that the effluent concentration should not be considered independent of the influent substrate concentration when heterogeneous cultures are used regardless of the techniques employed to measure the concentration of growth-limiting substrate. They suggested the use of regression equations to describe the interactions among influent COD, growth rate, and effluent COD at low growth rate conditions.

McKinney

Conventional waste treatment systems operate in the declining growth phase and microbial growth is controlled by the rate of addition of food. The rate of microbial growth is controlled by the concentration of unmetabolized food remaining. Recognizing this condition, a number of equations can be developed (7-9):

$$\frac{dMs}{dt} = KF \qquad (9)$$

where dMs/dt = rate of synthesis of microorganisms
F = concentration of unmetabolized food
K = growth rate constant

In addition,

$$\frac{dMs}{dt} = Ks\,\frac{dF}{dt} \tag{10}$$

where Ks = synthesis constant

Therefore

$$\frac{dF}{dt} = \frac{K}{Ks}(F) \text{ or } \frac{dF}{dt} = K'F \tag{11}$$

The removal of organic matter is related to the residual organic matter when the system operates in the declining growth phase.

In a completely mixed continuous flow system, the food removal equation is defined as:

$$F = \frac{Fi}{Km\cdot t + 1} \tag{12}$$

where F = the substrate concentration remaining unmetabolized
Fi = substrate concentration in influent
t = aeration time based on raw waste flow
Km = metabolism factor, temperature dependent

The mixed liquor suspended solids (MLSS) can be separated into four basic parts: the active mass (Ma); the endogenous mass (Me); the inert non-biodegradable organic suspended solids (Mi); and the inert, inorganic suspended solids (Mii). In a completely mixed aeration system (CMAS), the active mass, Ma, is related to the food metabolized, the length of aeration time of the sludge, and the rate of endogenous respiration:

$$Ma = \frac{KsF}{1/ts + Ke} \qquad (13)$$

where ts = sludge aeration time
Ke = endogenous respiration factor

The endogenous mass can be related to the active mass in the CMAS system:

$$Me = 0.2 \cdot Ke \cdot Ma \cdot ts \qquad (14)$$

Obviously Km, Ks, and Ke are key factors in these equations. These values were summarized by Burkhead (30) (Table 1) and are based on the treatment of domestic sewage at 20°C.

Table 1. CONSTANTS SUGGESTED FOR USE IN THE DESIGN FOR THE TREATMENT OF DOMESTIC WASTES

CMAS constant	Mathematical definition	Physical significance	Values
Km Metabolism constant	$\frac{Fi - F}{F \cdot t}$	Food removal rate	$\frac{15.0}{hour}$
Ks Synthesis constant	$K \cdot Km$	Rate of food converted into microbial cells	$\frac{10.4}{hour}$
Ke Endogenous Constant	$\frac{Ks \cdot F - \frac{Mv}{ts}}{Mv - 0 \cdot 2 \cdot Ks \cdot F \cdot ts}$	endogenous solids build up rate	$\frac{0.02}{hour}$

Mv is the volatile mass in the system, i.e., Ma + Me + Mi. The inert, non-biodegradable organic suspended solids can be obtained by:

$$Mi = (Mi_{inf})(ts/t) \tag{15}$$

where Mi = inert, non-biodegradable organic suspended solids in the reactor
Mi_{inf} = inert, non-biodegradable organic suspended solids in influent
ts = sludge retention time
t = raw waste aeration time

The inert, inorganic suspended solids can be determined by:

$$Mii = (Mii_{inf})(ts/t) + 0.1(Ma + Me) \tag{16}$$

where Mii = inert, inorganic suspended solids
Mii_{inf} = inert, inorganic suspended solids in influent; ash fraction of influent suspended solids

The oxygen uptake rate can be described as:

$$\frac{dO}{dt} = \frac{1.5(Fi - F)}{t} - \frac{1.42(Ma + Me)}{ts} \tag{17}$$

where dO/dt = oxygen uptake rate

The effluent BOD can be expressed as:

$$BOD_{eff} = F + K \cdot Ma_{eff} \tag{18}$$

where BOD_{eff} = BOD_5 in effluent
Ma_{eff} = oxygen demanding microbial mass in effluent
K = BOD_5 factor, 0.8, a constant since the BOD test is always at 20°C

CMAS systems are stable, easy to operate, and capable of producing a high quality effluent consistent with normal variations in organic and hydraulic loadings. Design of CMAS systems can be accomplished by Equations 12-18.

Many studies have been conducted with simple substrates such as glucose or acetate. However, insoluble and particulate contaminants are contained in most wastewaters and must be taken into account when the constants of these equations are evaluated. This is especially true with animal wastes and wastewaters.

Eckenfelder

Additional relationships have been developed (3, 5, 6, 31, 32) to describe aerobic biological systems. In a completely mixed, continuous flow system, the substrate removal relationship can be defined as:

$$Se = \frac{So}{1 + K \cdot Xv \cdot t} \quad \text{or} \quad \frac{So - Se}{Xv \cdot t} = K \cdot Se \qquad (19)$$

where So = influent substrate concentration
Se = aeration basin and system effluent substrate concentration
Xv = mixed liquor volatile suspended solids
t = liquid retention time in aeration basin
K = substrate removal rate

The factors which affect the value of K include the temperature, waste characteristics, volatile material stripped from the waste, and the turbulence level in the system. Volatile suspended solids or other appropriate measures of microbial active mass must be considered instead of total suspended solids when K is evaluated.

Volatile sludge accumulation can be defined as:

$$\Delta Xv \cdot V = a \cdot Sr \cdot Q - b \cdot x \cdot Xv \cdot V \qquad (20)$$

where ΔXv = volatile suspended solids accumulation
V = volume of aeration basin
a = mass yield rate or yield coefficient, BOD_5 basis
Sr = $SO - Se$ = substrate removed
Q = influent flow rate
b = endogenous respiration rate coefficient
x = biodegradable fraction of volatile suspended solids
Xv = mixed liquor volatile suspended solids

and

$$\frac{\Delta Xv}{xXv} = \frac{1}{SRT} \qquad (21)$$

where SRT is the sludge retention time or sludge age. When the system is operated as a once-through system,

$$SRT = t = \frac{1}{D} \qquad (22)$$

where t = liquid retention time and D = dilution rate.

These equations must be used with an understanding of the way they were developed and the constraints in their use:

-"b" should be applied only to the degradable portion of the volatile suspended solids

-"x" can be related to sludge age and F/M ratio

-when the influent waste contains degradable volatile suspended solids, "x" should be experimentally determined instead of calculated

-the yield coefficient, "a" must be defined as related to BOD, COD, TOC, or other parameters describing the organic substrate

-the yield coefficient, "a" generally is determined without including the influent volatile suspended solids in the wastewater. If these solids were included, the reported values of "a" will be different and the inclusion of the solids should be noted in the determination of "a"

-when the endogenous respiration coefficient "b" is determined with volatile suspended solids present in the influent wastewater, the value of "b" must include both the breakdown and synthesis of the volatile suspended solids in the wastewater and the degradation of the biomass

-the value of "b" will be influenced by turbulence, dissolved oxygen level and temperature.

In a completely mixed, continuous flow system, the basic equation of oxygen demand is

$$Rr \cdot V = a' \cdot Sr \cdot Q + b' \cdot x \cdot Xv \cdot V \qquad (23)$$

where Rr = oxygen uptake rate
a' = synthesis oxygen demand rate, BOD_5 basis
b' = endogenous respiration oxygen demand rate

The range of values of a' is between 0.4 and 0.9 for several wastewaters. Nitrification will result in a larger value of a'.

In a completely mixed system, if only the carbonaceous effluent BOD is of concern, the effluent BOD can be described as:

$$BOD_{5e} = Se + fo \cdot Xve \qquad (24)$$

where BOD_{5e} = effluent BOD_5 concentration
fo = BOD_5 equivalence of effluent volatile suspended solids
Xve = effluent volatile suspended solids concentration

The BOD contributed by the effluent suspended solids can be related to sludge age and the type of suspended solids present in the effluent.

Comparison

The mathematical models proposed by McKinney and Eckenfelder have been examined by Goodman and Englande (31). They concluded that for practical purposes these two models are identical.

A review of available mathematical models to describe biological treatment systems (33) suggested that the Monod model is more suitable for the design of biological waste treatment process than those proposed by Eckenfelder and McKinney. The application of these concepts to animal wastewaters will be discussed in this report.

Summary

There are merits in all of the reviewed design approaches. Somewhat different assumptions underlie the development and use of each approach. Some of the major differences inherent in the application of the approaches to animal wastes are: a) the large amount of non-biodegradable material in the untreated waste, b) the significant amount of biodegradable solids in the waste which will undergo stabilization in a treatment process, and c) the high concentration of oxygen demanding nitrogen compounds in the wastes. Animal wastes are not the simple soluble substrates around which many theoretical design approaches have been developed.

The design approaches developed in this study will incorporate the following:

- The soluble and insoluble part of animal waste will be considered separately when the design parameters are evaluated.

- Time dependence of the non-degradable influent solids or COD degradation and the endogenous respiration rate of biomass will be considered.

- The total COD in the effluent, i.e., the soluble COD, the COD equivalent of biomass, the non-degradable and undegraded insoluble COD, and the COD for nitrite oxidation will be determined.

- Oxygen requirements will include the oxidation of soluble and insoluble substrate, microbial mass, NH_4-N, and NO_2-N.

Conventional Aerobic Treatment of Animal Wastes

The possible biological treatment processes for agricultural wastes have been summarized (34). They included oxidation ponds, aerated lagoons, oxidation ditches, anaerobic lagoons, anaerobic digesters, composting, and land disposal.

The land will be the ultimate disposal site for treated or untreated animal wastes. The degree of treatment needed prior to land disposal will be related to the degree of needed odor control or waste stabilization or nutrient control. Current aerobic treatment processes for animal wastes are long term aeration systems such as oxidation ditches or aerated lagoons. Present design parameters for these processes as animal waste treatment units are based on an organic loading rate to the reactor volume, or the number of animals per reactor volume, or reactor detention time. Oxygenation capacity has been estimated as twice the BOD_5 loading to the reactor.

Basic microbial growth rates, substrate removal rates, microbial oxygen demand rates, or oxidation of ammonia or nitrite have not been considered explicitly in available design parameters. The present study has been conducted to incorporate more of these fundamental parameters into the design of aerobic animal waste treatment systems.

MATERIALS AND METHODS

A. Batch Studies

Removal Kinetics Study -

The organic wastes used in this phase were obtained from poultry production units at Cornell University. The one or two-day old poultry manure was blended in a Waring blender for two minutes at low speed with tap water. Approximately 80 grams of manure was added to one liter of tap water. The blended mixture was filtered through a single layer of cheesecloth to remove the feathers and the large particulate matter. This filtered mixture was diluted with tap water to achieve the concentration needed for a given experiment. Where settled wastewater was desired, some of the filtered mixtures were settled for 30 minutes before the supernatant was decanted for use.

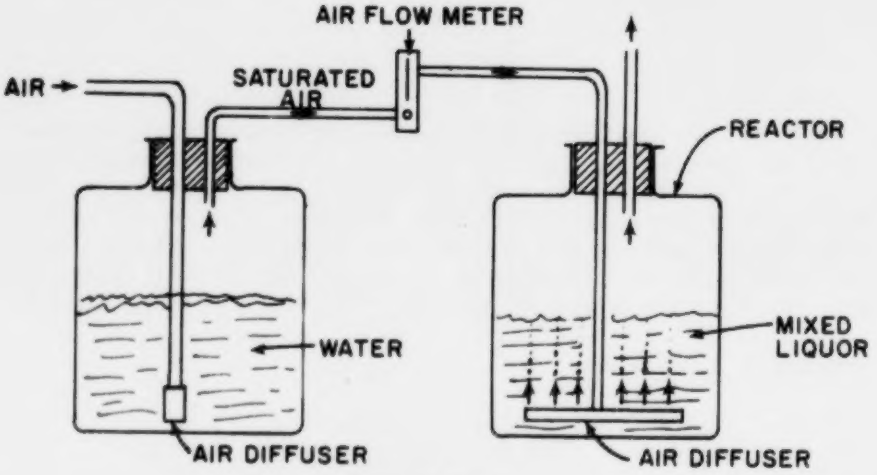
Two or 2.5 liters of the diluted mixtures were added to 5 liter batch study containers, aerated with humidified air, and a high level of dissolved oxygen maintained. A sketch of the apparatus is shown in Figure 2. The loss of any water due to evaporation was made up by adding distilled water.

Before sampling, the container was shaken by hand to assure complete mixing and homogeneous mixed liquor samples. Because of the large amount of particulate matter in the mixed liquor, a broken-tip-pipette was used for sampling.

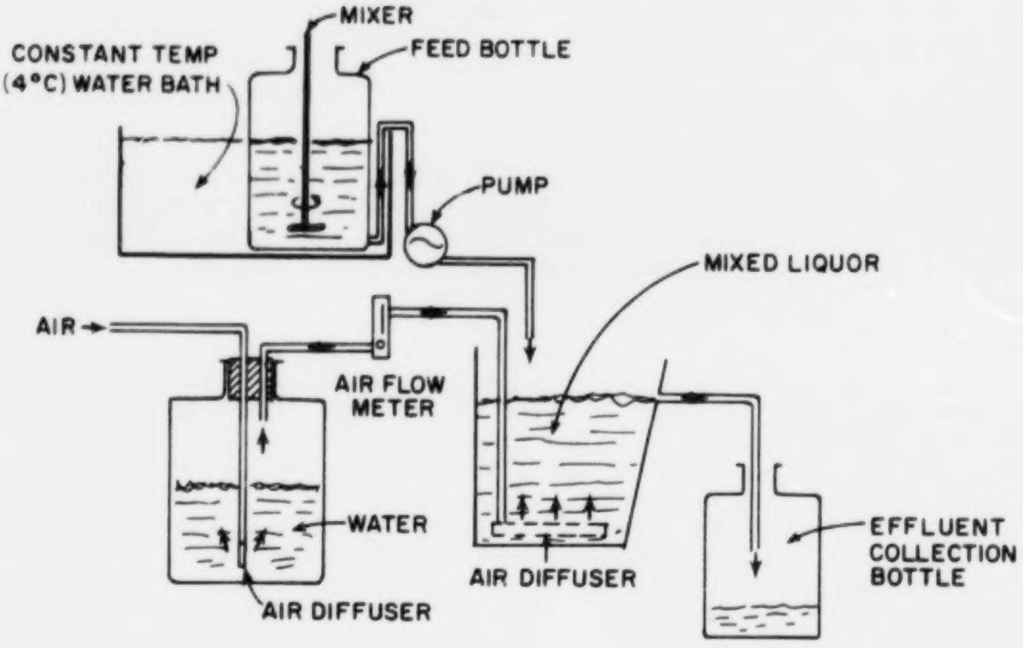
The COD of the total mixed liquor, the filtrate or soluble COD, the suspended solids concentration, the pH and the oxygen uptake rates were measured during the aeration period. For the determination of soluble COD, filtrates were obtained by filtering the samples through a 0.45μ filter paper. All the batch experiments were conducted at room temperature ($23° \pm 2°C$).

Initial Suspended Solids Concentration Study -

The mixed liquor taken from the poultry manure oxidation ditch of the Agricultural Waste Management Laboratory at Cornell University was diluted with


AIR FLOW METER
AIR
SATURATED AIR
REACTOR
WATER
MIXED LIQUOR
AIR DIFFUSER
AIR DIFFUSER

BATCH UNITS


MIXER
FEED BOTTLE
CONSTANT TEMP (4°C) WATER BATH
PUMP
MIXED LIQUOR
AIR
AIR FLOW METER
WATER
AIR DIFFUSER
AIR DIFFUSER
EFFLUENT COLLECTION BOTTLE

CONTINUOUS FLOW UNITS

Figure 2. Schematic of the experimental apparatus for laboratory aeration studies.

distilled water to the desired suspended solids concentration. Two liters of these diluted suspensions were added to a 5 liter container. An additional 1 liter of filtered, settled poultry manure mixture, prepared as described earlier, was added to each container. After the addition, the combined mixture was aerated using humidified air. Samples were taken for the analysis of COD and suspended solids concentration. Oxygen uptake rates and pH were measured directly in the containers.

Kinetic Constants Study -

For this phase of the study the settled poultry manure was centrifuged at 5000 rpm for 10 minutes. The filtrate was passed through a 0.45μ membrane filter, collected and diluted to obtain different concentrations. The filtrate was used as the substrate for these experiments. The batch apparatus shown in Figure 2 was used.

B. Continuous Flow Studies

Bench Scale Study -

The bench scale completely mixed continuous flow units employed in the study are shown in Figure 2. In this study no recycle of solids was provided. The laboratory units were located in a 20°C constant temperature walk-in chamber. Settled poultry manure was prepared as described earlier and used as feed.

During operation of the units, the feed flow rate was varied to study the effect of detention time on the COD and solids removal efficiency, and on the oxygen uptake rate. Every day or two, the feed was changed, the feed line was cleaned, and samples were taken for analysis.

Pilot Plant Study -

The oxidation ditch at the Agricultural Waste Management Laboratory receives the wastes from about 250 birds. The mixed liquor in the ditch is mixed and aerated by a cage rotor. The concentration of mixed liquor solids in the ditch was controlled by varying the water input and output. Thus different periods of equilibrium at varying mixed liquor solids concentration were obtained. The total and volatile solids, COD, pH, and oxygen uptake rate during these equilibrium periods were measured and used for the evaluation of the operational parameters. The temperature varied from 12°C in the winter to 25°C in the summer.

C. Analytical Methods

Suspended solids concentrations were determined by the membrane filter techniques as outlined in Standard Methods (35). The suspended solids contained an unknown fraction of dissolved solids. Total volatile solids and volatile suspended solids were determined as described in Standard Methods. The COD of the samples was determined by using the rapid method (36). The pH of the sample was measured with a Corning pH meter. Dissolved oxygen measurements were obtained by a galvanic cell oxygen analyzer (Precision Scientific Co.) for the laboratory units and by a YSI Oxygen Meter (Model 54) at the oxidation ditch.

RESULTS

Batch Studies

Removal Kinetics -

Project personnel hypothesized that degradation of liquid poultry waste was a sequential removal process in which both the soluble and insoluble waste components undergo different rates of degradation. The overall removal mechanism may be described as the rapid microbial metabolism of the soluble substrate followed by the subsequent aerobic stabilization of the synthesized biomass and the original, degradable organic solids present in the waste.

Since the poultry waste contained bacteria which were capable of metabolizing the wastes, no inoculum was needed. The study on the removal characteristics of COD and suspended solids was conducted by preparing the different poultry waste suspensions and conducting batch aeration studies. Three units were initially loaded with unsettled suspensions of 5, 10, and 50 grams of poultry manure per liter. Three other units were initially loaded with settled suspensions of 20, 40, and 60 grams of poultry manure per liter. Figure 3 illustrates results typical of the unsettled suspensions and Figure 4 indicates typical results of the settled suspensions.

The removal pattern shown in these Figures can be approximated by first order kinetics. For the settled poultry manure data, the growth of microbial solids can be noted within the first two days of aeration. Such an increase was not observed with the unsettled manure suspensions. The unsettled suspensions contained a greater amount of solids than what their corresponding settled suspensions would have contained, and this higher amount of solids in conjunction with the error involved in the determination of suspended solids may have masked the actual increase in microbial solids that occurred.

The ratio of soluble COD removed to total COD removed for these six batch experiments averaged 0.389. Therefore about 39% of the total removal of the organics contained in these wastes was due to the degradable, soluble COD in the waste and about 61% was due to the degradable particulate material in these wastes.

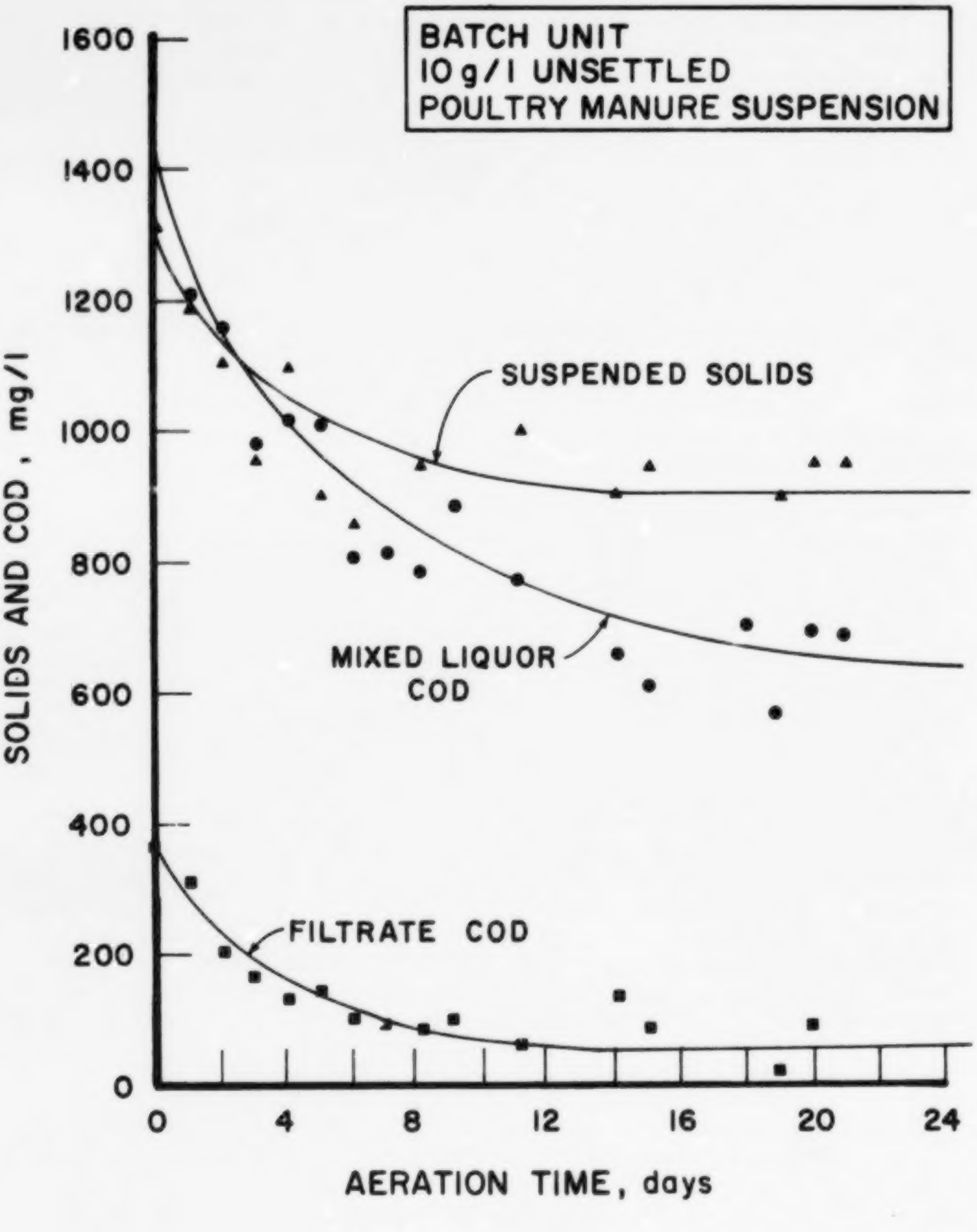


Figure 3. General removal characteristics (solids and COD) of unsettled poultry manure suspension.

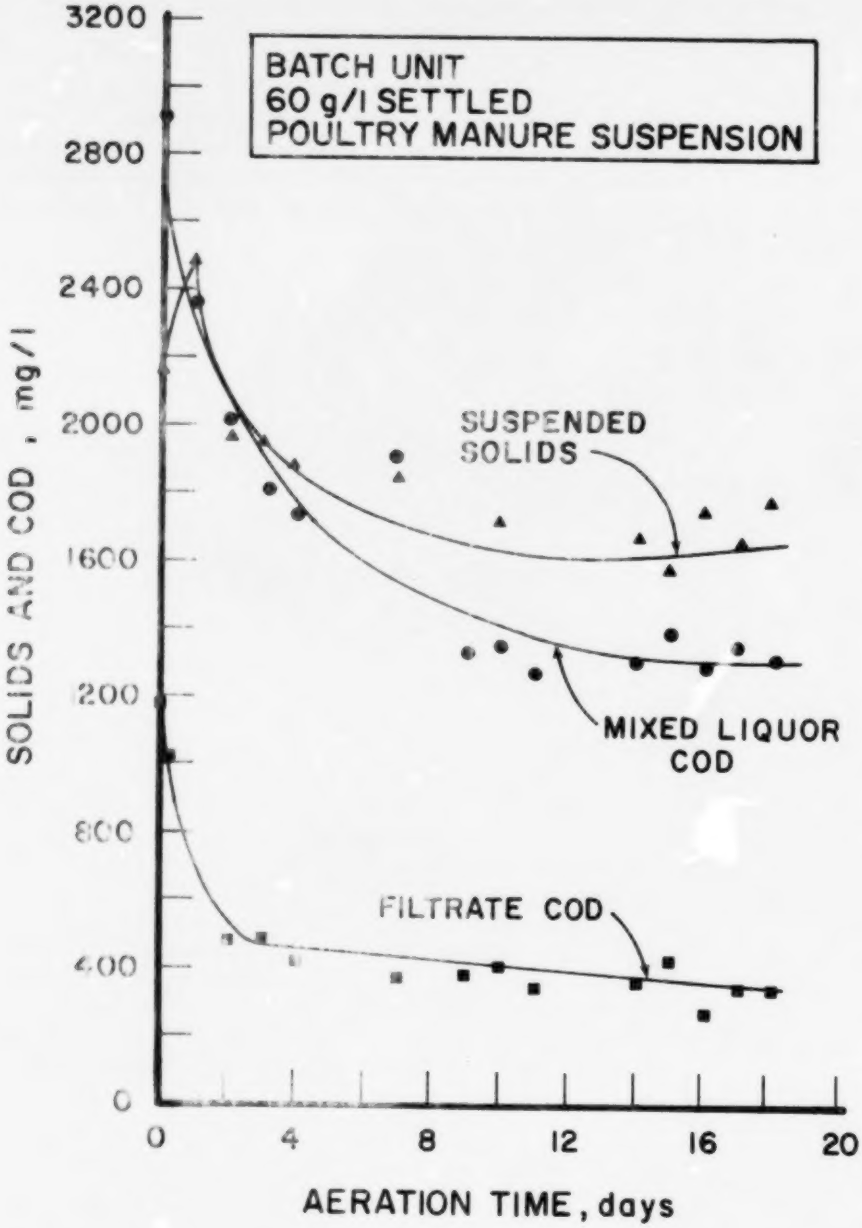


Figure 4. General removal characteristics (solids and COD) of settled poultry manure suspension.

A residue of mixed liquor COD, soluble COD, and suspended solids occurred. The biodegradability of this residue is unknown, but is assumed to be minimal.

The COD and solids removals have been approximated as an apparent first order reaction. With this assumption, the removal constants were determined with and without considering the non-biodegradable material in the units. Without considering the non-biodegradable materials, the following relationships describe the change or removal in total and filtrate COD and suspended solids.

$$\ln \frac{St}{So} = -Kt \qquad (25)$$

$$\ln \frac{Ft}{Fo} = -K't \qquad (26)$$

$$\ln \frac{Xt}{Xo} = -K''t \qquad (27)$$

where So = mixed liquor COD at time zero
St = mixed liquor COD at time t
F = filtrate COD
X = suspended solids concentration
K = rate constant for removal
K' = rate constant for degradation
K'' = rate constant for oxidation

Close analysis does not completely support the assumption of a first order reaction. When the data is plotted on semi-logrithmic paper, more than one removal rate becomes obvious (Figures 5 and 6). Two or more removal rates occur in the long term aerobic treatment of poultry manure. The different rates are due to the differences in degradability of the waste components.

If the non-biodegradable material in the units is considered, another set of equations results. The COD and suspended solids never become zero, but equilibrate to a specific residual level. The difference between the concentration of the initial COD or solids and the residue represents the biodegradable material. Removal kinetics should be based on the biodegradable fraction, i.e.,

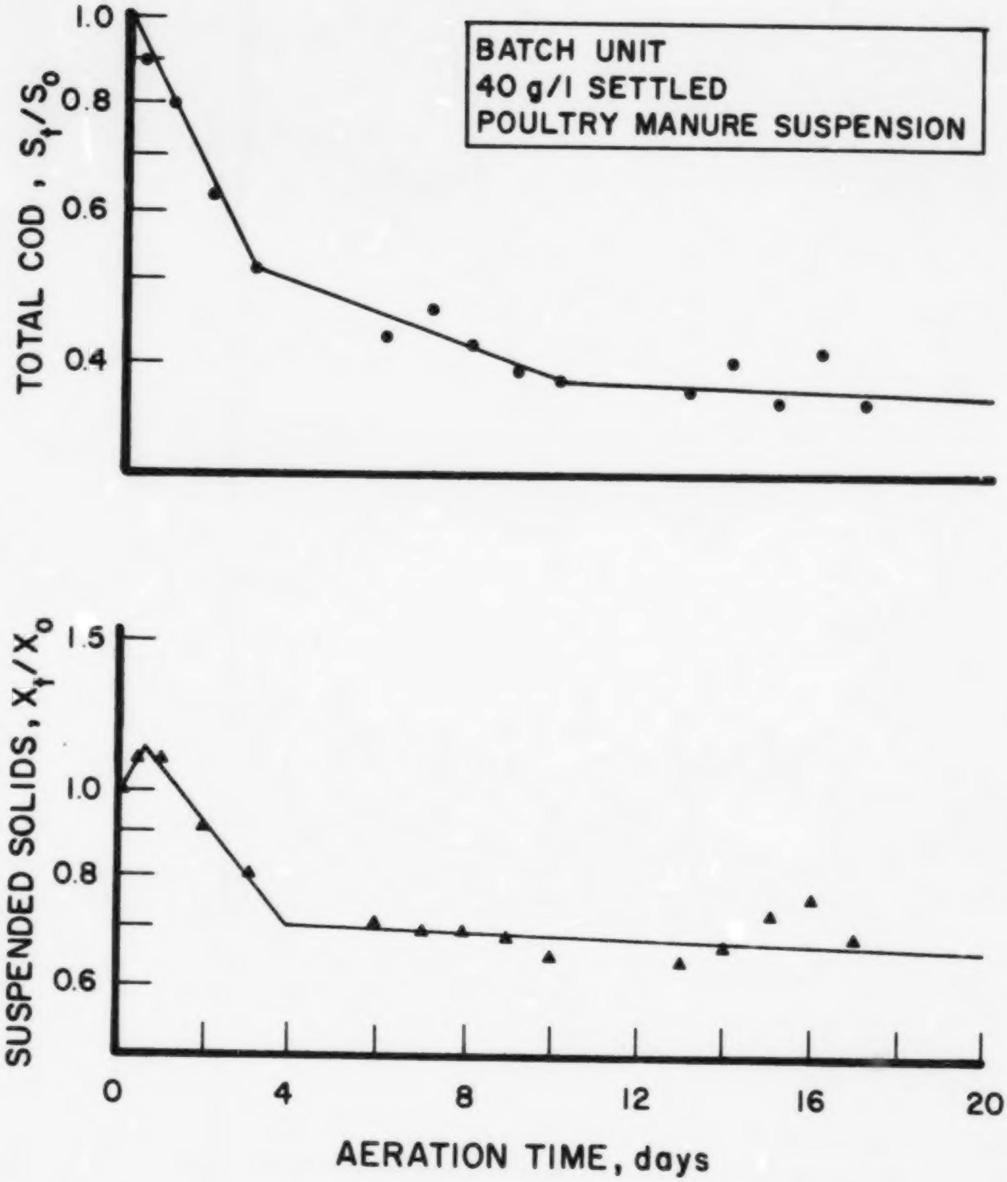


Figure 5. Removal characteristics of total COD and suspended solids - semi-logarithmic plot.

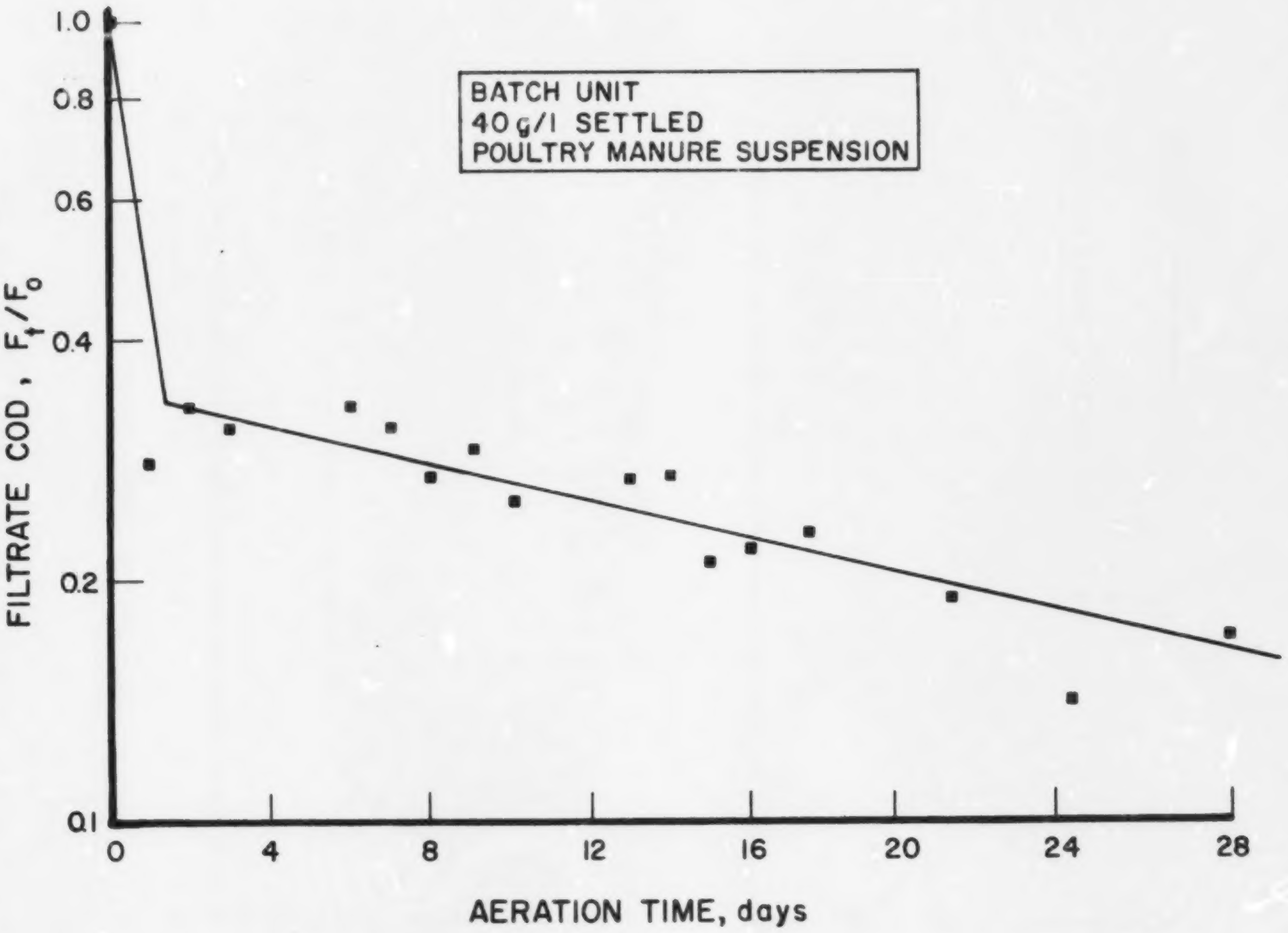


Figure 6. Semi-logarithmic plot of soluble COD removal.

$$\ln \frac{St - Si}{So - Si} = Kit \qquad (28)$$

$$\ln \frac{Ft - Fi}{Fo - Fi} = Ki't \qquad (29)$$

$$\ln \frac{Xt - Xi}{Xo - Xi} = Ki''t \qquad (30)$$

where Si = total COD
Fi = soluble COD
Xi = suspended solids

The values of these residues were determined from graphs such as those in Figures 3 and 4. When the residues are considered, an apparent simple logrithmic removal relationship resulted (Figure 7).

The effect of considering the residue in evaluating substrate removal kinetics is illustrated in Table 2. The removal rates calculated when the residue was considered were higher than when the residue was not considered. In addition, the total COD removal rates of the settled suspensions were larger than those of the unsettled suspensions. The unsettled suspensions contained particulate matter that may have degraded at a slower rate thus lowering the overall COD removal rate. The settled suspensions contained a larger amount of soluble COD per unit of suspended solids (Table 2). Soluble and readily available material is more easily degraded than the particulate matter that is not amenable for easy degradation. Therefore substrate removal kinetics for the treatment of poultry manure should consider the residue that will result after extensive treatment and stabilization. Rate constants developed from soluble substrate studies are not directly applicable to wastes such as poultry manure which contains particulate matter that undergoes decomposition slowly. Consideration of both the soluble and particulate fractions of poultry manure is necessary in the design of aerobic treatment systems for these wastes.

The initial ratio of COD to suspended solids was useful in explaining differences in the removal rates of settled and unsettled manure suspensions. However, the parameter used for design of aerobic units should be expressed as the ratio of oxygen demanding material in the influent waste to the microorganisms in the reactor. Practically this is expressed as the F/M ratio or in these experiments, the total #COD/#suspended solids, or gm total COD/gm suspended solids.

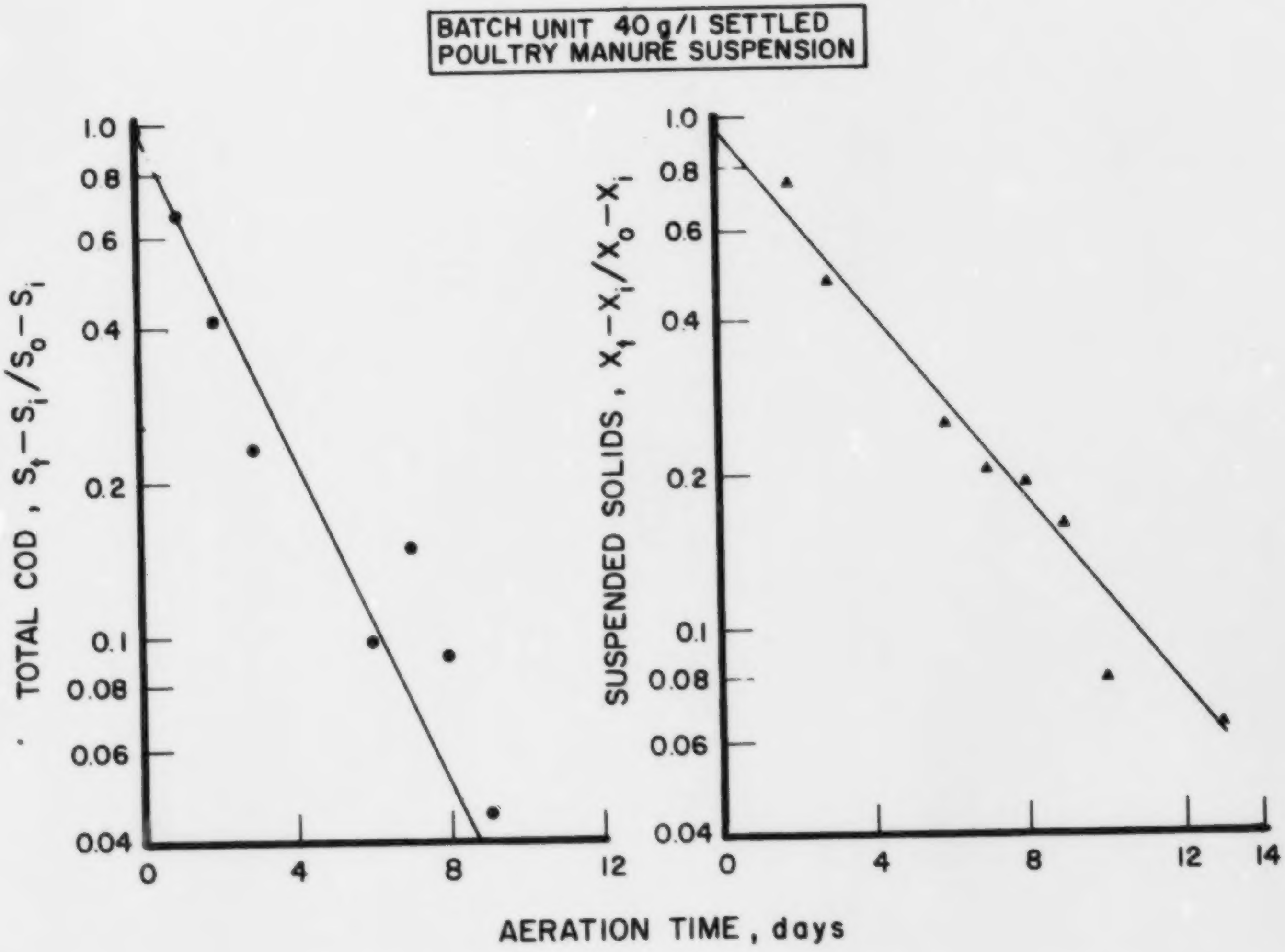


Figure 7. Removal characteristics of total COD and suspended solids with consideration of the residues.

Table 2. COMPARISON OF TOTAL COD REMOVAL RATE CONSTANTS

Type of poultry manure suspension	Initial Total COD mg/l	$\frac{\text{Initial Soluble COD}}{\text{Initial Suspended Solids}}$	K (day^{-1})	Ki (day^{-1})
Settled	2100	0.46	0.327	0.560
Settled	4080	0.39	0.233	0.370
Settled	3170	0.50	0.184	0.392
Unsettled	1210	0.35	0.156	0.274
Unsettled	1530	0.28	0.115	0.215
Unsettled	11460	0.29	0.116	0.206

K = removal rate without consideration of residue
Ki = removal rate with consideration of residue

To investigate the effect of the above loading rate on the removal of COD and influent solids, a series of batch experiments were conducted with different initial loading rates. Mixed liquor from the pilot plant oxidation ditch was used to assure adequate acclimated organisms and settled poultry manure was used as the waste. The influence of the loading rates on the COD and suspended solids removal rates are noted in Figures 8 and 9. Only the removal rates for the first two phases are noted because rates of subsequent phases, if any, were considered insignificant. The removal rate of total COD and suspended solids increased with an increase in the initial organic loading rate. The removal rate of filtrate COD decreased with an increase in loading rate.

Constants for the Monod Equations -

The soluble, degradable portion of poultry manure suspensions is the immediately available substrate for microbial growth. Growth patterns and kinetic constants can be developed using the soluble fraction of these wastes. The constants can be helpful in the design of biological treatment units to obtain desired effluent characteristics.

Poultry manure suspensions were centrifuged and filtered to provide the substrate for these series of experiments. Mixed liquor from a laboratory continuous flow unit treating poultry wastes was used to provide adequate organisms. Batch experiments were conducted, the microbial growth pattern was determined, and the Monod growth kinetic constants (Y, μm, Ks) were obtained. In these experiments the initial filtrate COD concentrations were 135, 225, 458, and 1565 mg/l. Typical results are noted in Figure 10.

When the suspended solids were plotted on semilogrithmic paper (Figure 11), the growth rate constants "μ" were determined at the different initial substrate concentrations. Only data for the initial microbial growth period was used for the determination of "μ".

A plot of the growth rates versus initial substrate concentration indicated a hyperbolic relationship. A "Lineweaver-Burk" plot of these parameters provided a straight line (Figure 12) that was used to determine "μm" and "Ks" as shown. The yield constant "Y" was evaluated by the relationship between the change in suspended solids per unit change in filtrate COD during the microbial growth period (Figure 13).

Thus for the soluble COD in poultry manure wastewater, as identified by the centrifuged and filtered fraction, the maximum microbial growth rate, "μm", was 0.35/hour, the "Ks" value was 895 mg/l, and the yield constant, "Y" was 0.41 milligram of suspended solids increase per milligram of COD removed.

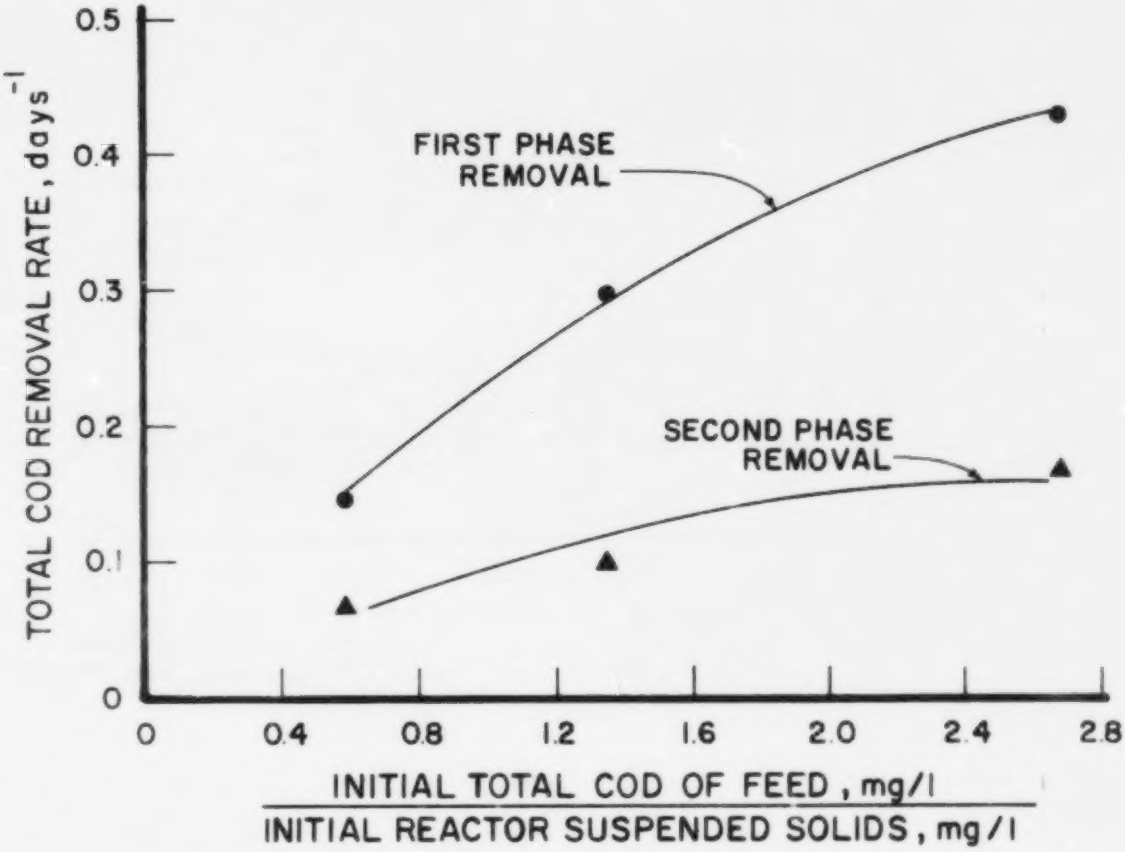


Figure 8. Relationship between total COD removal rate and total COD loading.

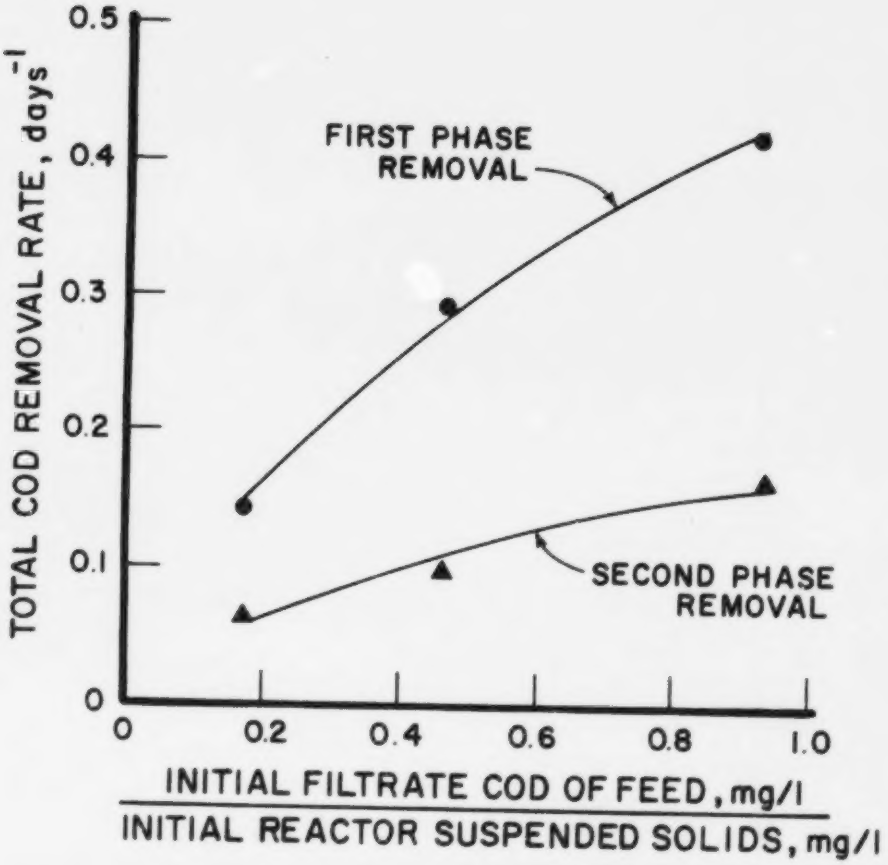


Figure 9. Relationships between filtrate COD removal rate and filtrate COD loading

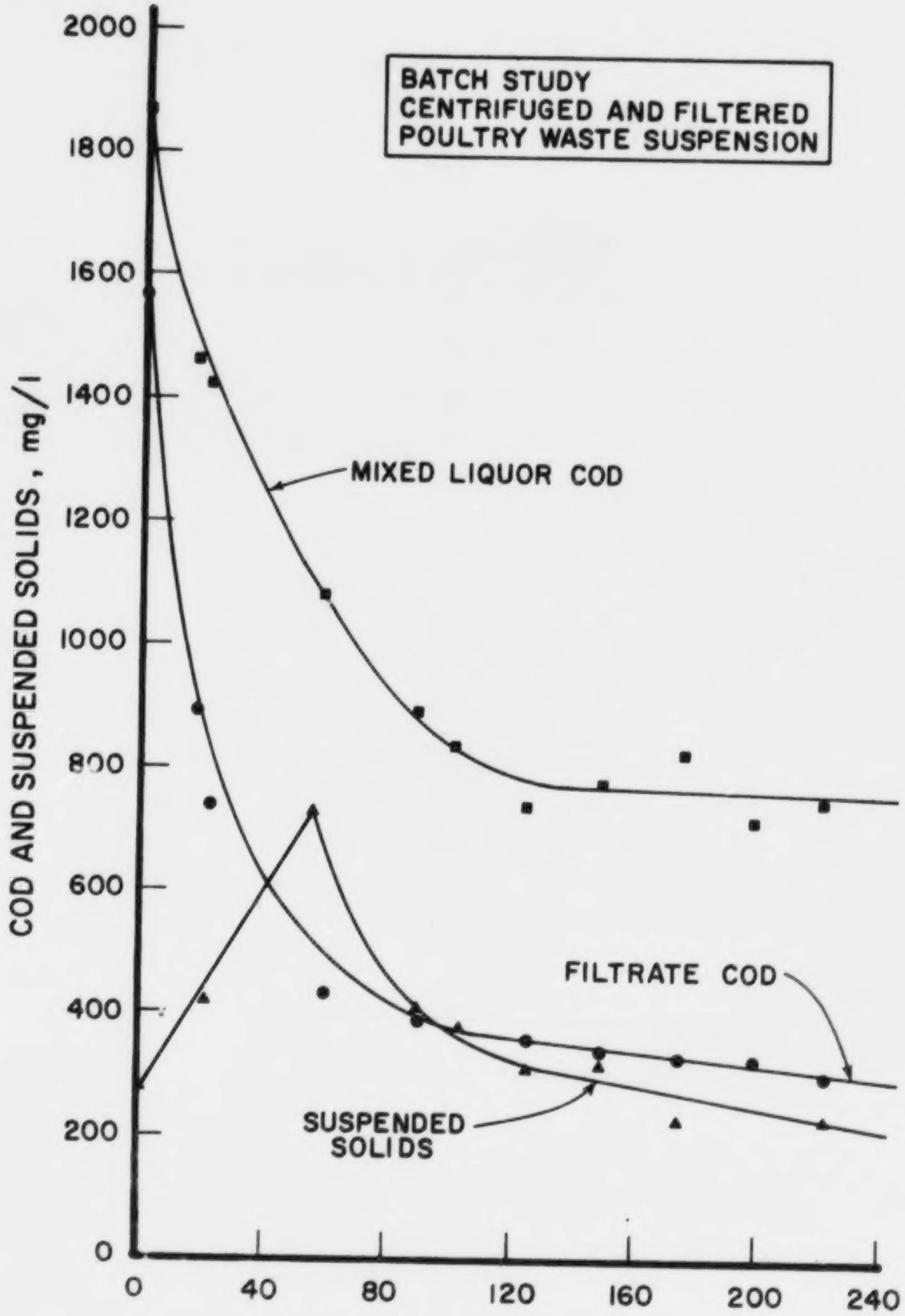


Figure 10. Removal characteristics of soluble poultry waste suspension

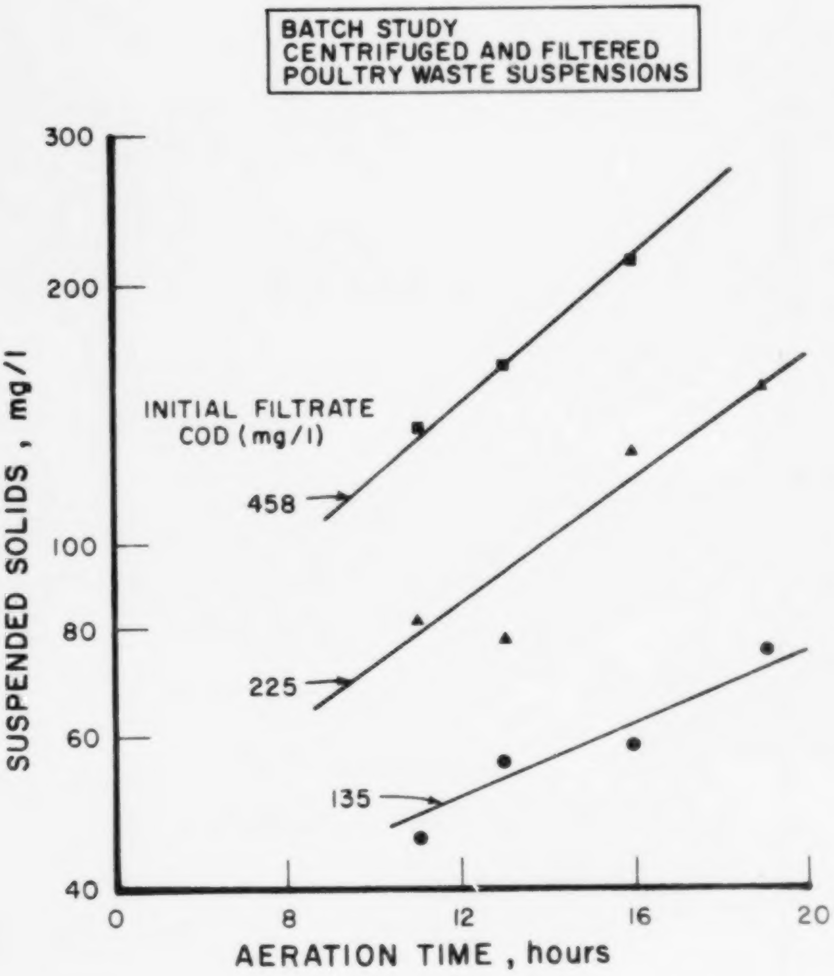


Figure 11. Graphical estimation of different specific growth rates by using different initial filtrate COD

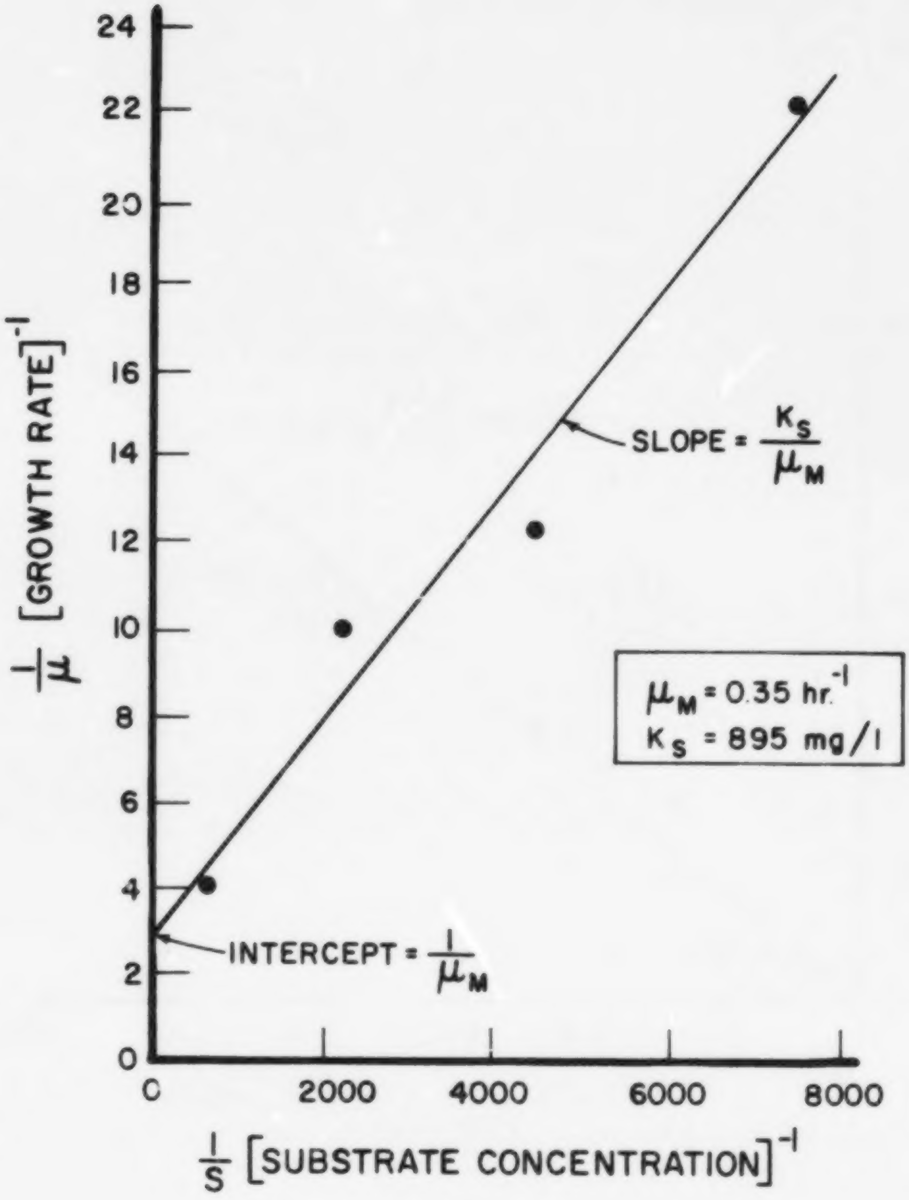


Figure 12. Graphical estimation of Monod kinetic constants.

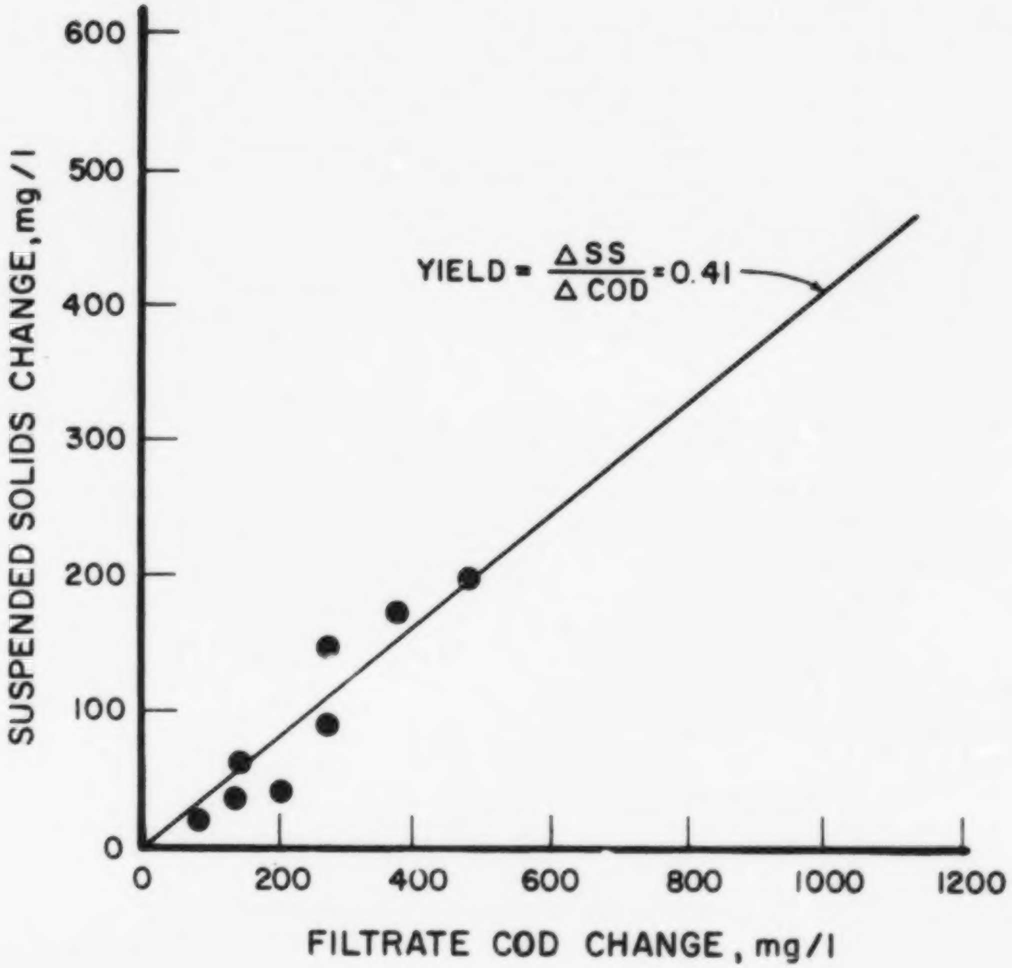


Figure 13. Graphical estimation of the microbial yield value.

Oxygen Demand -

The metabolism of the organic waste creates an oxygen demand which must be met by an aeration device in aerobic treatment. The oxygen demand is related to the loading rate of a unit. The oxygen uptake rates, in terms of mg/l/hour and mg/gram suspended solids/hour, were determined for the batch experiments described earlier. The variation in these uptake rates as a function of aeration time are shown in Figure 14. The greatest oxygen demand in terms of mg/l/hour occurred immediately after the units were fed. The uptake rate in terms of mg/gSS/hour was the greatest in the most heavily loaded unit. The maximum demand rate per unit solids occurred several hours after the units were started.

After the solids became stabilized, i.e., after about 16 hours of aeration the oxygen demand was in the range of 1.0 to 6.0 mg of oxygen/gram suspended solids/hour and in the range of 8-14 mg/l/hour. These rates are similar to those reported during the aerobic stabilization of primary and secondary sewage sludges. These residual oxygen demand rates are related to the endogenous demand of the microorganisms while the earlier higher demand rates were due to the synthesis of the microorganisms and the rapid uptake of the soluble matter.

Thus aerobic treatment units with short detention times will have high oxygen demand rates. If the oxygen supply is inadequate to meet the demand, aerobic conditions will not be obtained. Biological units treating animal wastes generally have long liquid detention times due to the low waste volume. Under these conditions, oxygen demand rates will be low provided the combination of degradable waste is low. The oxygen demand is also related to the loading rate of the treatment unit.

Continuous Flow Studies

General -

Batch studies are useful in determining the general patterns of substrate removal for specific wastes. However, practical waste treatment systems are continuous flow processes. Patterns and removal relationships developed from batch studies should be compared with results of continuous flow studies to evaluate their applicability. Two types of continuous flow units were used in this phase of the study--laboratory units and a pilot plant oxidation ditch.

Laboratory -

The laboratory unit was fed settled poultry manure to avoid clogging of feed lines and unnecessary variations in the influent waste parameters. After 38 days of operation, the pH in the reactor started

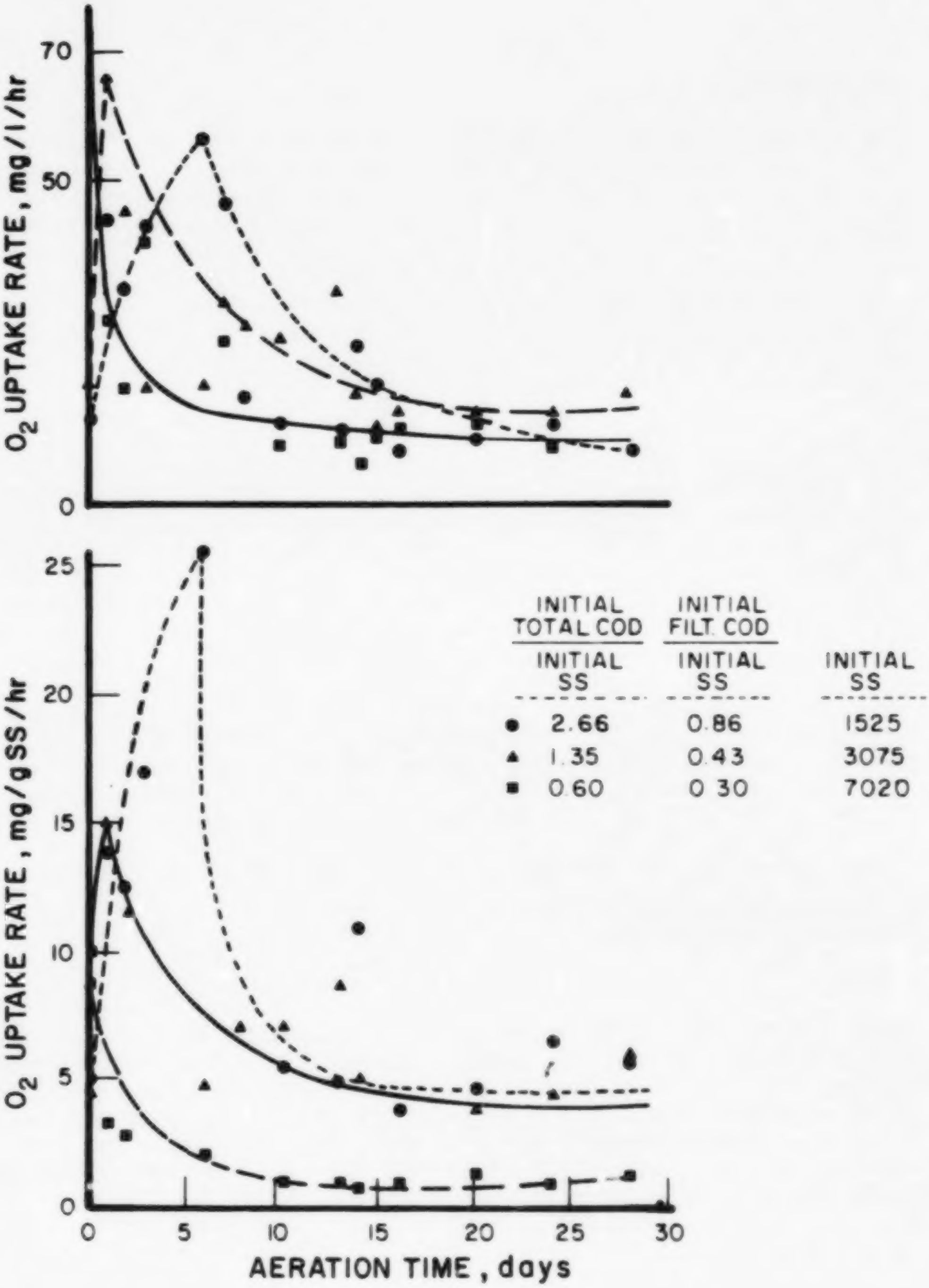


Figure 14. Oxyegen uptake rate related to aeration time.

to decrease and the filtrate COD in the reactor increased. Obviously the process of nitrification occurred in the system. To observe the effect of increasing flow rate on the performance of the system and to obtain more operational data, the mixed liquor of the original unit was split into two units, subsequently called Unit I and II. The flow rate to these units also was varied during the remainder of the study.

The general characteristics of the units are noted in Figure 15. The loading rate of the units varied because of the change in flow rate and had an effect on the removal efficiencies (Figure 16). The removal of COD and suspended solids increased as the loading rate decreased.

The COD removal efficiency was calculated on the basis of total influent COD and total mixed liquor COD leaving the unit. The COD removal efficiencies would have been greater had the filtrate COD values been used since most of the COD in the mixed liquor was due to the solids fraction rather than the soluble fraction. In a long detention time treatment system, the influent soluble COD has been converted into microbial cell mass.

Filtrate COD was not used to estimate removal efficiencies since the filtrate contained nitrite and the COD values of the filtrate would have included the oxidation of the carbonaceous matter and the nitrite. Because of the small amount of carbonaceous matter, the inclusion of nitrite oxidation would introduce erroneous or at least non-comparable results since the influent COD did not contain nitrites. Although the mixed liquor also included the nitrites, the COD of the solids fraction was large and including the nitrite did not introduce a significant error.

The relationships between the organic loading rate to the units and the oxygen uptake rates are noted in Figure 17. The uptake rate, in terms of mg/l/hr, increased rapidly as the loading rate increased. At the lower loading rates, the oxygen uptake rate was essentially that due to solids degradation. When the uptake rate per unit suspended solids was compared to the loading rate, a straight line relationship occurred. The higher loading rates increased the solids concentration which resulted in the linear relationship. The oxygen uptake rates obtained in this continuous flow study are comparable to those obtained in the batch study experiments.

Pilot Plant -

The details of the pilot plant oxidation ditch are outlined in this report and have been published elsewhere (37). During this portion of the study, the oxidation ditch was operated at various solids levels to evaluate the

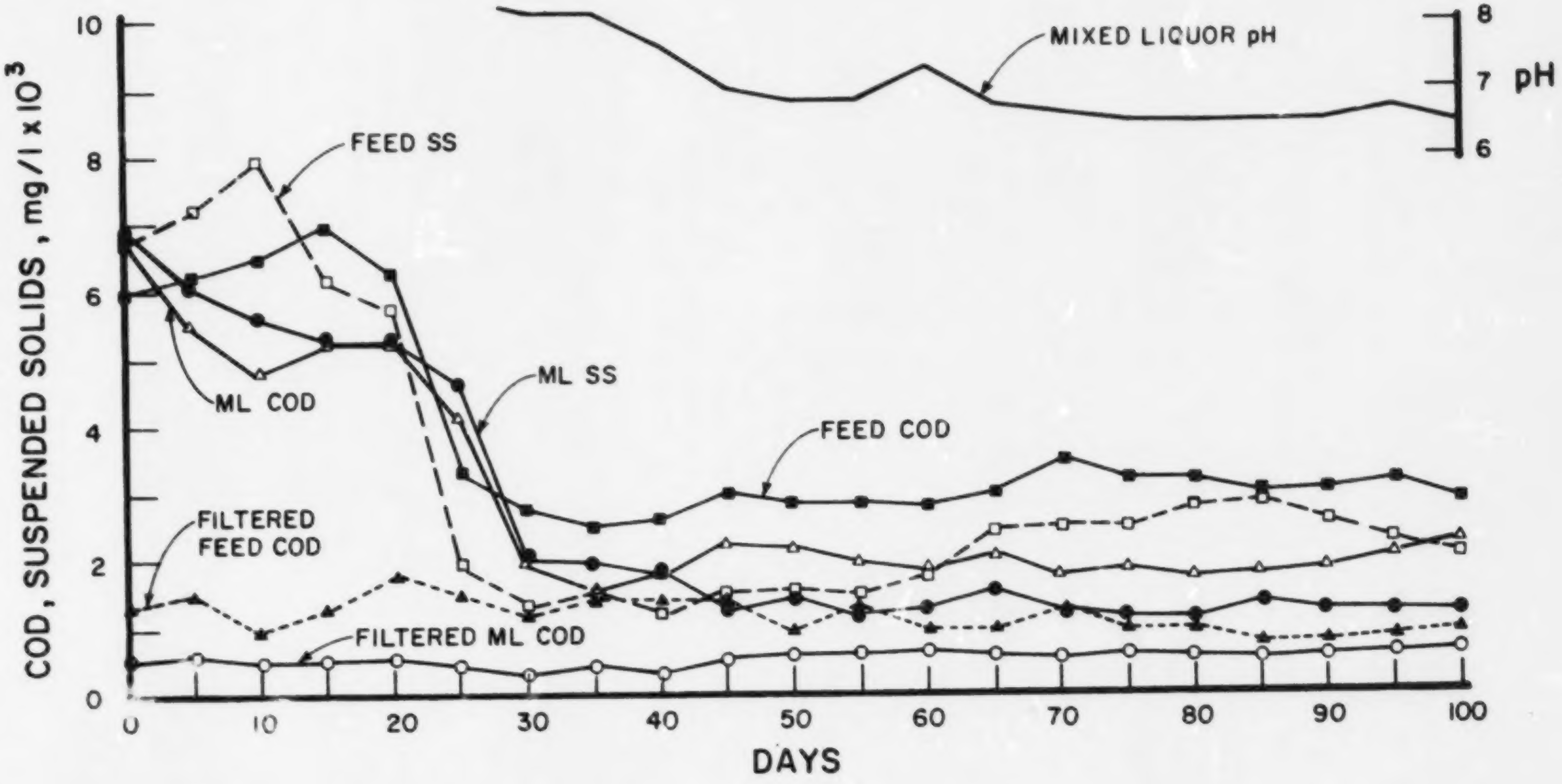


Figure 15. Operational parameters of laboratory continuous flow units - unit I.

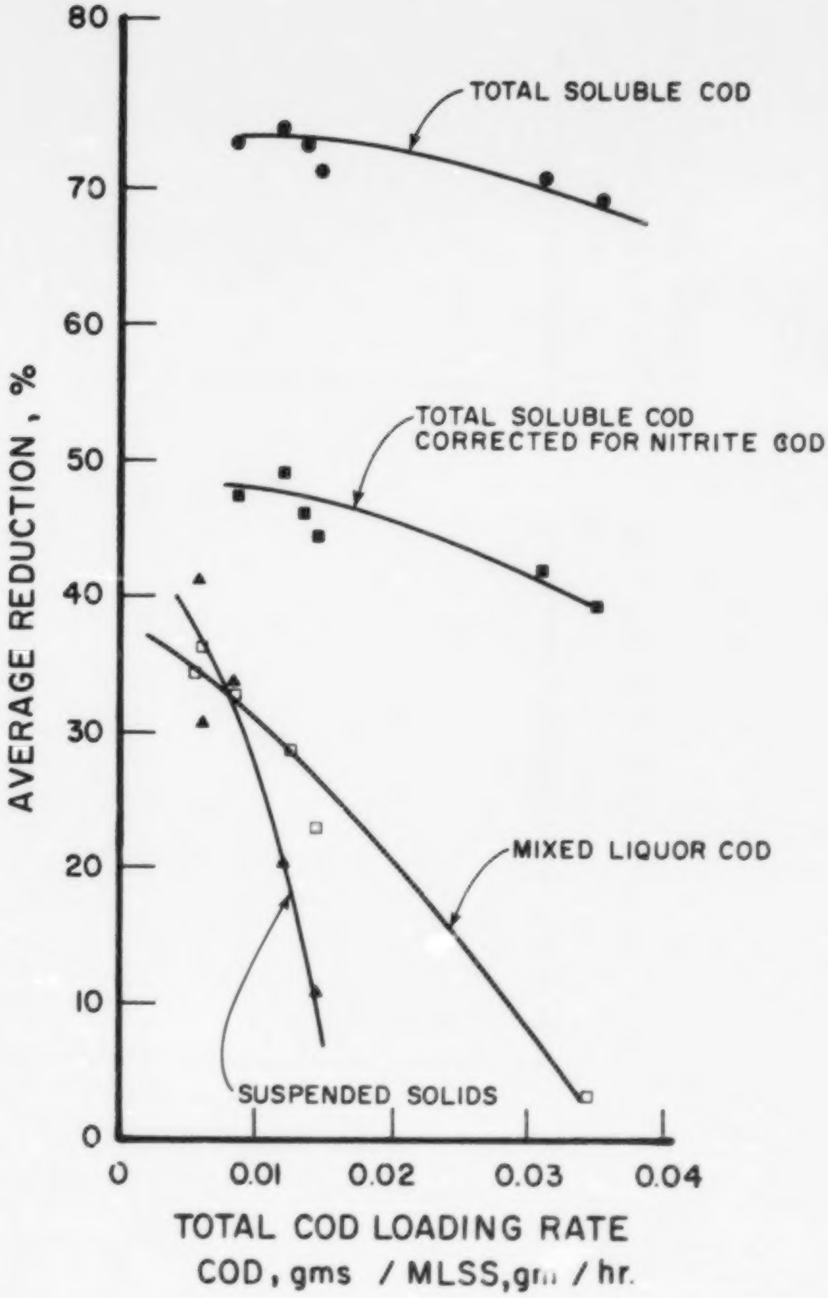


Figure 16. COD and suspended solids reduction as related to total COD loading rate.

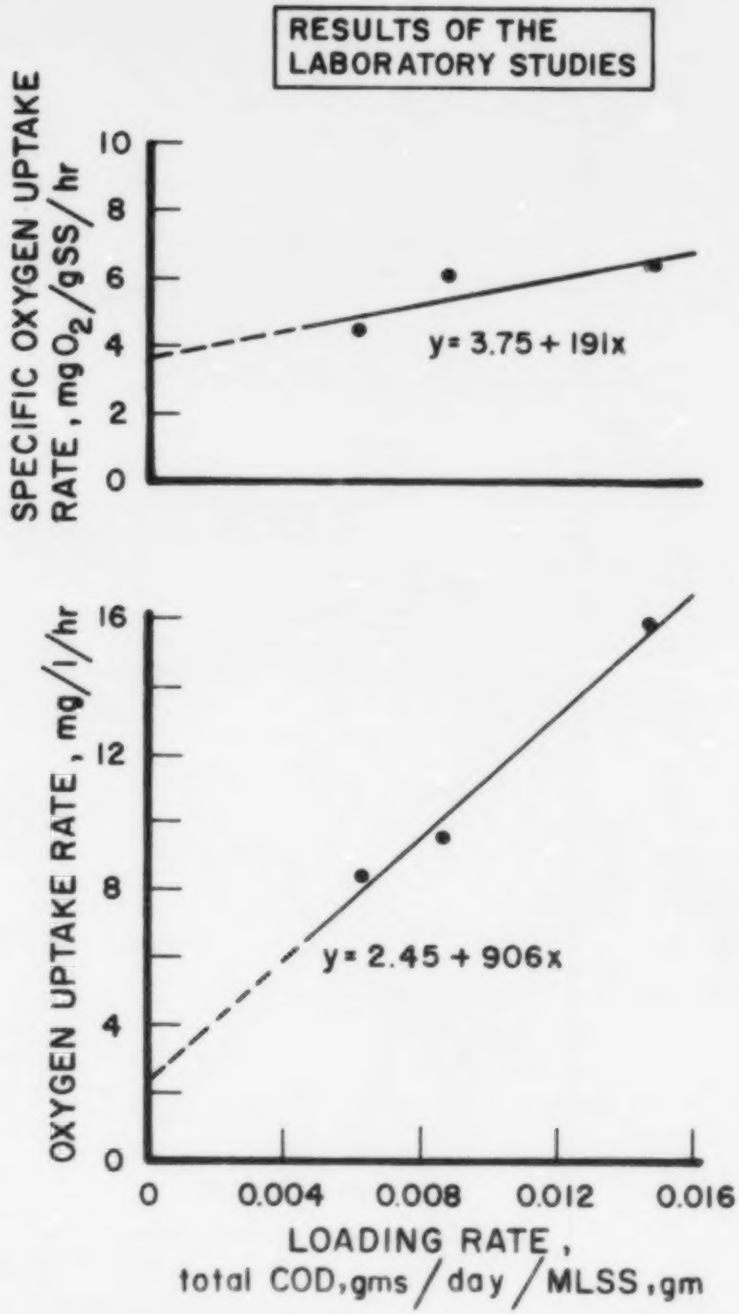


Figure 17. Relationship between oxygen uptake rate and organic loading rate - continuous flow units.

magnitude and characteristics of the overflow, the oxygen transfer characteristics, nitrification, and the removal efficiency of the total COD and total solids. The solids concentration in the ditch was controlled by an automatic overflow and water addition.

Equilibrium conditions occurred at each solids level. The mixed liquor characteristics during these periods were used to evaluate operational parameters and removal efficiencies. Typical patterns during such periods are shown in Figure 18. The average and range of characteristics for all the equilibrium periods are noted in Table 3.

The effect of the hydraulic retention time at the noted flow rates on performance efficiency is illustrated in Figure 19. The removal of all parameters increased as the liquid detention time increased.

General Design Equations

General -

In the previous section describing the batch studies, the COD and suspended solids removal could be approximated by a first order reaction if the solids and COD residue of the studies were considered. The solids fraction contributed the largest amount of the total COD.

A completely mixed reactor without recycle, such as the continuous laboratory and pilot plant oxidation systems can be described by the sketch in Figure 20. At steady state equilibrium conditions, mass balance equations can be used to evaluate the removal constants, or if removal constants are known or assumed, to determine effluent characteristics.

For total COD, the equation becomes:

$$F \cdot Si \cdot \Delta t = F \cdot \bar{S} \cdot \Delta t + K \cdot \bar{S} \cdot V \cdot \Delta t \tag{31}$$

where Δt = aeration time in days for the period under consideration
K = total COD removal rate, day^{-1}

This equation can be rearranged to solve for either the effluent total COD concentration or the removal constant depending what is desired and known, i.e.:

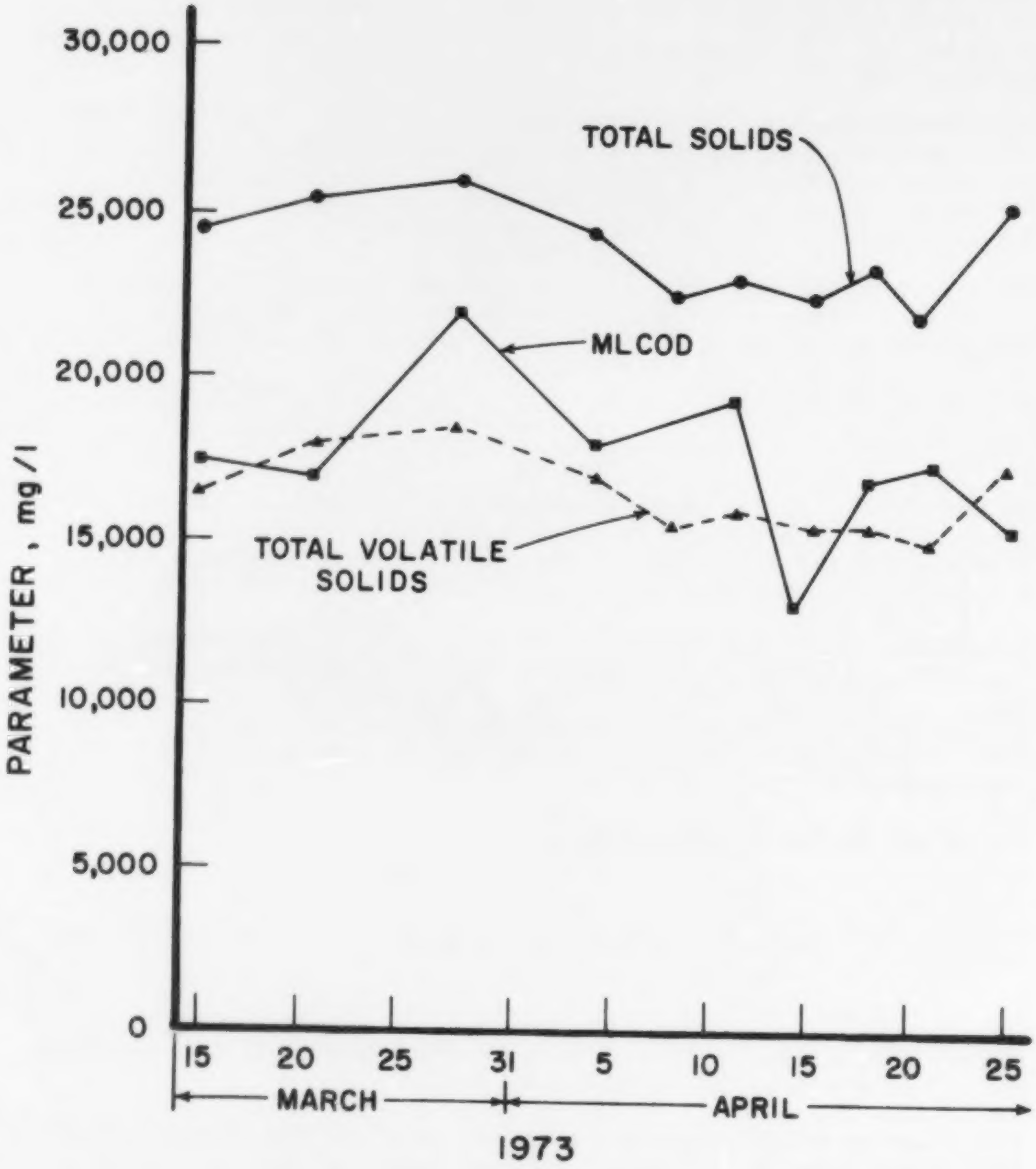


Figure 18. General operational characteristics of COD and solids in the oxidation ditch.

Table 3. PILOT PLANT OXIDATION DITCH CHARACTERISTICS DATA DURING EQUILIBRIUM PERIODS

Date (1972)	Water flow rate (liters/day)	Mixed liquor COD (mg/l)		Total solids (mg/l)		Total volatile solids (mg/l)	
		ave.	range	ave.	range	ave.	range
3/14 to 5/2	208.2	18,900	13,900 - 25,600	25,400	17,900 - 30,700	17,700	15,700 - 20,000
5/9 to 6/23	151.4	26,000	23,500 - 30,600	33,400	30,500 - 36,700	21,800	20,100 - 23,300
6/27 to 7/11	104.1	27,600	23,600 - 31,200	38,400	36,900 - 39,300	23,900	22,400 - 24,200
7/18 to 7/25	66.2	29,200	28,100 - 29,900	41,500	40,400 - 43,100	24,300	24,100 - 24,800
7/28 to 8/29	94.6	28,600	26,900 - 30,400	42,400	41,200 - 43,900	25,300	24,000 - 26,500

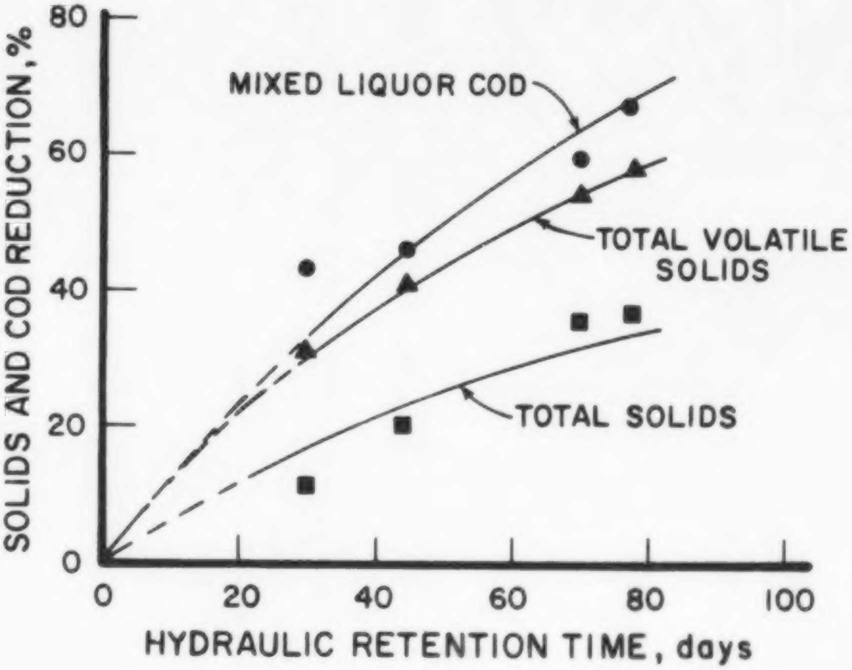
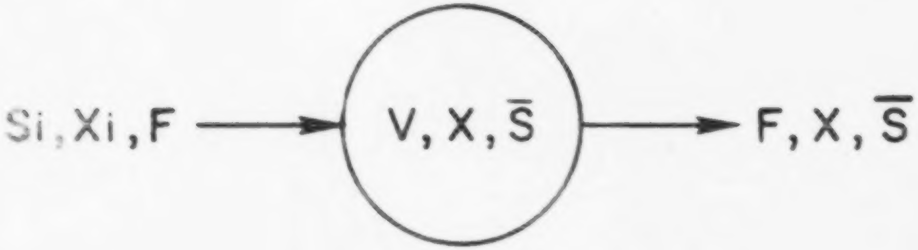


Figure 19. Effect of hydraulic retention time on the COD and solids reduction - oxidation ditch.



S_i = TOTAL COD IN THE INFLUENT, mg/l

X_i = INFLUENT SUSPENDED SOLIDS, mg/l

F = FLOW RATE, l/day

V = REACTOR VOLUME, liters

X = REACTOR AND EFFLUENT SUSPENDED SOLIDS, mg/l

$\bar{S}$ = TOTAL COD IN THE REACTOR AND EFFLUENT, mg/l

Figure 20. Schematic of a completely mixed continuous flow reactor without recycle.

$$\bar{S} = \frac{Si}{1 + \frac{K \cdot V}{F}} = \frac{Si}{1 + K \cdot t} \qquad (32)$$

where t is the hydraulic retention time of the system and

$$K = \frac{Si - \bar{S}}{\bar{S} \cdot t} \qquad (33)$$

Results from the previous laboratory project (38) and from the laboratory studies in this project phase permit "K" to be evaluated from Equation 33 and to be related to the organic loading of the units in terms of gms COD/day/gms mixed liquor volatile suspended solids. The relationship is shown in Figure 21. An equation of the form

$$K = 0.017 + 0.11X \qquad (34)$$

appeared to fit the parameters with a correlation coefficient of 0.976. The value of the intercept (0.017) can be interpreted as an estimate of the COD autooxidation rate of the mixed liquor solids.

Loading rates up to 1.1 gms COD/day/gms MLVSS were evaluated. The data were obtained from two studies conducted at an interval of two years apart. The correlation coefficient of 0.976 indicated that the equation relating the two parameters adequately explains their interaction. Thus Equation 32 should be able to be used to predict the total COD removal efficiency or in the effluent of a system treating poultry wastes.

In the same manner a comparable equation can be developed from a mass balance on solids at equilibrium conditions:

$$X = \frac{Xi}{1 + \frac{K' \cdot V}{F}} = \frac{Xi}{1 + K' \cdot t} \qquad (35)$$

where K' is the removal coefficient of suspended solids and

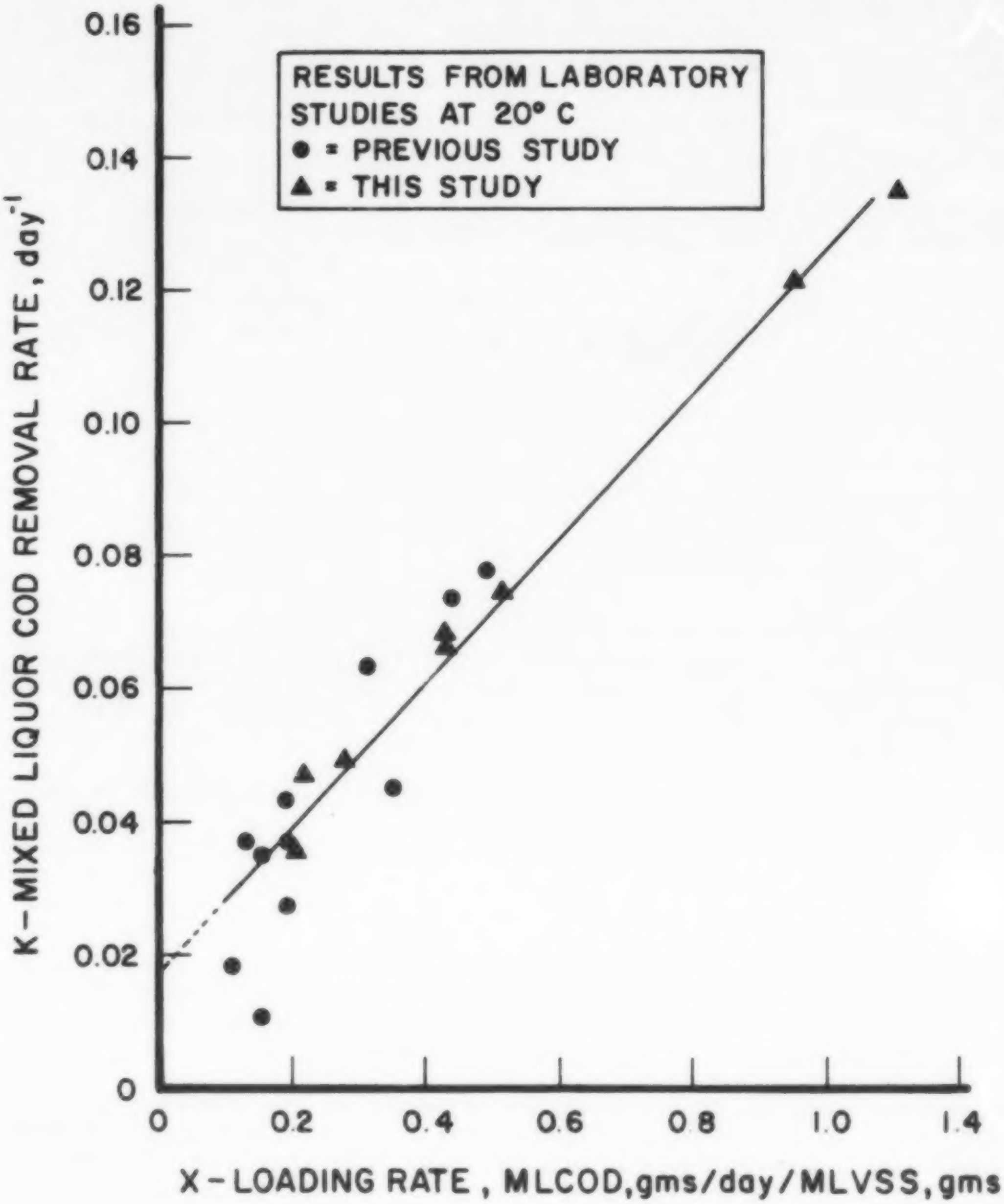


Figure 21. Rate of mixed liquor COD removal as related to COD loading rate.

$$K' = \frac{Xi - X}{X \cdot t} \qquad (36)$$

With appropriate parameters known, either the effluent solids concentration or the removal constant K' can be determined.

The relationship between K' and the organic loading rate, X', was evaluated (Figure 22). An equation of the form

$$K' = 0.011 + 0.15X' \qquad (37)$$

appeared to fit with a correlation coefficient of 0.76. In this equation, X' refers to the loading rate, gms of total COD/day/gm of MLVSS. The value of the intercept again can be interpreted as an estimate of the autooxidation rate of the mixed liquor solids, this time in terms of solids rather than COD degradation rate.

These relationships which were developed under laboratory conditions (Figures 21 and 22) were applied to the pilot plant oxidation ditch data to determine their validity under practical situations. Table 4 indicates the results of a comparison and suggests that the above relationships can be applied to actual situations.

The relationship between the oxygen requirements and the organic loading rate has been compared for the laboratory units (Figure 17) and the oxidation ditch (Figure 23). The differences between the results obtained from the laboratory and oxidation ditch data are due to the fact that different substrates were used in each case. Settled poultry wastewater was used in the laboratory studies and untreated poultry wastes were added directly to the oxidation ditch. Different oxygen requirements would result from the demand of the different substrates and the data are not directly comparable. In addition, the loading rates in the two studies covered different ranges and different measures of solids had to be used.

As expected, the oxygen requirements increased as the loading rate increased. The requirements based on the oxidation ditch data were much closer to the laboratory data on a per unit solids basis (mg O_2/gram SS/hr) than they were on a mg/l/hr basis. In the practical situation, such as in the oxidation ditch, the oxygen requirements ranged between 30-40 mg/l/hr and between 1-3mg O_2/gram TVS/hr over a loading of up to 0.13 gms of total COD/gm of MLVSS/day. These ranges provide an estimate of the oxygen requirements likely to be experienced in field situations.

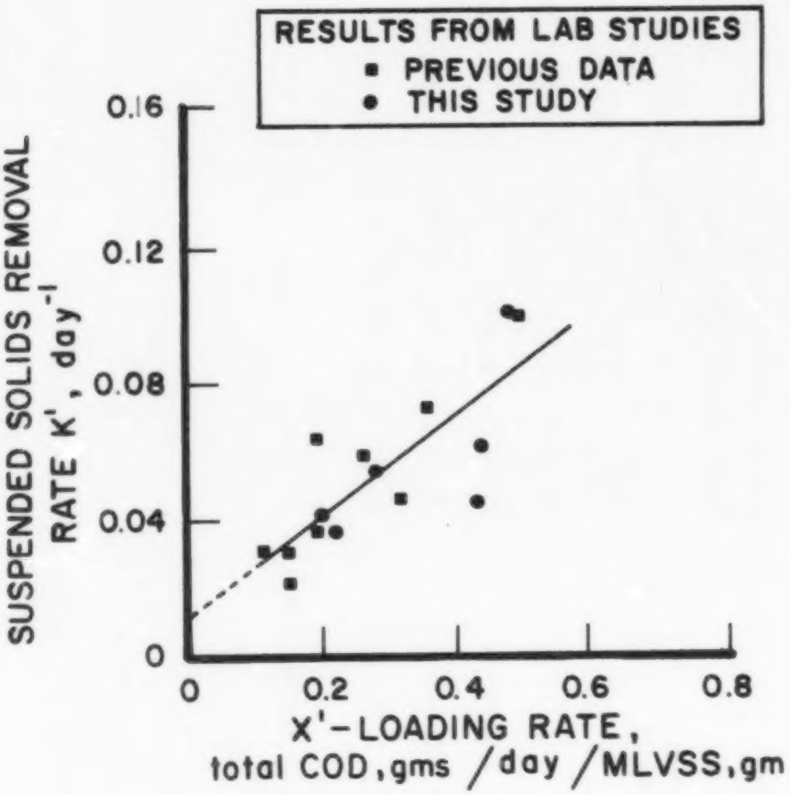


Figure 22. Suspended solids removal rate as related to COD loading rate

Table 4. APPLICATION OF DESIGN EQUATIONS FOR TOTAL COD AND SUSPENDED SOLIDS TO RESULTS FROM THE PILOT PLANT OXIDATION DITCH

Date of equilibrium period (1973)	Loading rate gms total COD/day/gm MLVSS	MLCOD in the effluent, mg/l			SS in the effluent, mg/l		
		est.	meas.	$\frac{\text{estimated}}{\text{measured}}$ (%)	est.	meas.	$\frac{\text{estimated}}{\text{measured}}$ (%)
3/15 - 4/20	0.129	16,300	17,560	92.0	12,770	11,950	106.8
5/9 - 6/16	0.088	21,580	25,540	84.5	17,200	16,290	105.5
7/4 - 7/11	0.067	25,040	25,240	99.2	20,760	19,190	108.1
7/28 - 8/29	0.061	26,270	28,800	91.2	22,080	20,980	105.2

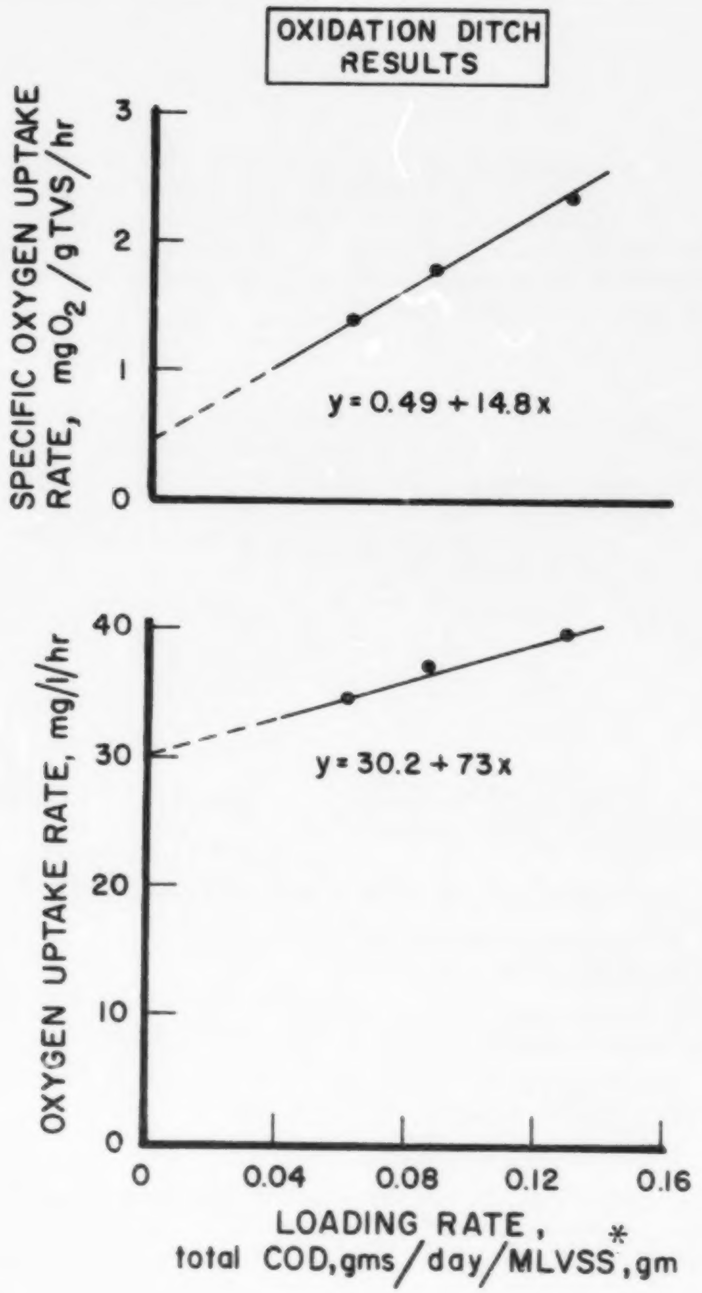
Conditions used for this estimation

a) 250 birds

b) TS = 2·SS

c) VSS = 0.75 SS (based on TVS = 0.75·TS)

d) equations developed in the laboratory study were used to estimate the parameters



* based on the assumptions noted in Table 4.

Figure 23. Oxygen uptake rate as related to COD loading rate.

The above mass balance equations provide an opportunity to determine removal constants, effluent characteristics, and oxygen demand for the aerobic treatment of poultry manure. In the following sections, the results of the laboratory and pilot plant experiments will be used to compare other approaches developed by Monod, McKinney, and Eckenfelder to design aerobic waste treatment systems.

Monod -

The growth of microorganisms during the metabolism of the soluble fraction of poultry manure suspensions has been found to follow kinetic relationships developed by Monod. Therefore the soluble part of the substrate and the microbial solids concentration in effluent of a completely mixed, continuous flow reactor can be estimated by using Equations 4-8 presented earlier in this report.

$$\bar{S}_{11} = \frac{Ks \cdot D}{\mu m - D} \qquad (38)$$

$$X_{11} = Y(Si_{11} - \bar{S}_{11}) \qquad (39)$$

where $\bar{S}_{11}$ = degradable soluble COD in the effluent, mg/l
Ks = saturation constant, mg/l
μm = maximum growth rate, hr^{-1}
D = dilution rate, hr^{-1}; (hydraulic detention time)$^{-1}$
X_{11} = biomass concentration in the effluent, mg/l
Y = yield constant
Si_{11} = degradable soluble influent COD

The change in the total COD ($\bar{S}$) in the reactor can be expressed as follows using the system described in Figure 20:

Change of total COD in the reactor = input of total COD - output of total COD

-Change of degradable, soluble COD in the reactor for energy and synthesis of microbial mass - change of degradable, insoluble COD in the reactor for energy and synthesis of microbial mass - overall autooxidation of total COD in the reactor, (i.e., oxidation of microbial mass and degradable influent organic solids when organic loading is zero) i.e.

$$V \cdot \frac{d\overline{S}}{dt} = F \cdot Si - F \cdot \overline{S} - \frac{d\overline{S}_{11}}{dt} V - \frac{d\overline{S}_{21}}{dt} V - Kd \cdot \overline{S} \cdot V \qquad (40)$$

where $\overline{S}_{11}$ = degradable soluble COD in the reactor or effluent
$\overline{S}_{21}$ = degradable insoluble COD in the reactor or effluent
Kd = overall auto-oxidation rate of total COD in the reactor

The degradable insoluble COD in the reactor ($\overline{S}_{21}$) consists of microorganisms plus any influent insoluble COD that has not yet been degraded. The degradation rate of this material is not rapid and probably contributes little to the overall growth of the microorganisms. With this assumption, $\overline{S}_{21}$ can be neglected and Equation 40 rewritten under equilibrium conditions.

$$F(S_i - \overline{S}) = V(\frac{\mu \cdot X_{11}}{Y} + Kd \cdot \overline{S}) \qquad (41)$$

Since $F/V = D$, $\mu = D$, $X_{11} = Y(Si_{11} - \overline{S}_{11})$, $\overline{S}_{11} = \frac{Ks \cdot D}{\mu m - D}$, and $Si_{11} = \alpha Si$

where α is the fraction of the soluble degradable COD in the influent, and X_{11} is the microbial solids that are synthesized. Inclusion of these relationships in Equation 41 results in:

$$\overline{S} = \frac{D}{D + Kd} [(1-\alpha)Si + \frac{Ks \cdot D}{\mu m - D}] \qquad (42)$$

Using Equation 42, the total COD in the effluent of a completely mixed continuous flow system can be estimated if the appropriate constants are known.

The change in total suspended solids in the reactor can be expressed in a similar manner:

$$V \cdot \frac{dX_{VSS}}{dt} = F \cdot Xi_{2VSS} + \mu \cdot X_{11} \cdot V - F \cdot X_{VSS} - Kd \cdot X_{VSS} \cdot V \qquad (43)$$

where Xi_{2VSS} = nondegradable influent VSS

In Equation 43 it was assumed the Xi_1, the degradable influent volatile suspended solids (VSS), can be oxidized without significantly increasing the soluble COD in the reactor. It was assumed that when the degradable influent solids are metabolized, the soluble COD that results will be used for microbial growth at the same rate as the initial soluble COD. As noted from the batch experiments discussed earlier, the rate of removal of soluble COD was greater than that of particulate matter, thus soluble COD resulting from degradation of the particulate matter should not accumulate in the reactor.

Assuming that the system is operated under steady state conditions, Equation 43 can be modified to:

$$D(Xi_{2VSS} + X_{11} - X_{VSS}) = Kd \cdot X_{VSS} \qquad (44)$$

Using α as before, β as the volatile fraction of the suspended solids in the reactor (X_{VSS}/X_{SS}), and "fi" as the undegraded fraction of the influent volatile suspended solids (Xi_{2VSS}/X_{VSS}), the suspended solids in the reactor and the effluent can be expressed by:

$$X_{SS} = \frac{\beta \cdot D}{D + Kd}\left[fi(Xi_{VSS}) + \alpha \cdot Y \cdot Si - \frac{Y \cdot Ks \cdot D}{\mu m - D}\right] \qquad (45)$$

"fi" includes both the undegraded fraction of the influent volatile suspended solids and the undegraded fraction of the synthesized microbial solids. "fi" was operationally defined using the batch laboratory data as the ratio of the volatile suspended solids in the reactor at any detention time "t" to the initial SS in the reactor at time zero.

The change of the soluble portion of the total effluent COD can be expressed as follows, under steady state conditions:

$$\overline{S}_1 = Si_1 - Si_{11} + \frac{D \cdot Ks}{\mu m - D} \tag{46}$$

where $\overline{S}_1$ = soluble COD in the effluent
Si_1 = soluble COD in the influent

Equation 46 differs from Equation 38 in that Equation 38 estimates the unmetabolized soluble degradable COD in the effluent, $\overline{S}_{11}$, and Equation 46 estimates the total soluble COD, $\overline{S}$, which includes the biodegradable and non-biodegradable COD, in the effluent.

Equations 42, 45, and 46 can be used to estimate the total COD, total suspended solids, and total soluble COD in the effluent if μm, Ks, α, β, Kd, Y, and fi are known. The only variable available to those who will design aerobic treatment systems is the dilution rate which is equal to one over the detention time (hydraulic detention time).

The "undegraded" portion of volatile suspended solids "fi" in the influent is hard to define because it was obtained only during a specific aeration period (Figure 4). It is possible that some of this material could be degraded if the aeration period were longer. The value of "fi" should be related to the aeration period in a logrithmic manner. Using data from this study, Figure 24 was developed. An equation of the form

$$fi = 0.967 \cdot t^{-0.157} \tag{47}$$

fit the data with a correlation coefficient of 0.924.

Using the previously developed kinetic constants for the Monod equations, and the equation for "Si", Equations 42 and 45 were used to calculate the effluent total COD and suspended solids that should result. These calculated results were compared to the data obtained from the continuous flow laboratory experiments. The comparison was done using the residuals, i.e., the difference, between the measured values and the predicted values. These residuals were compared to detention time of the units to evaluate any particular trends (Figure 25). The source of the constants used to predict the results were determined as noted in Table 5.

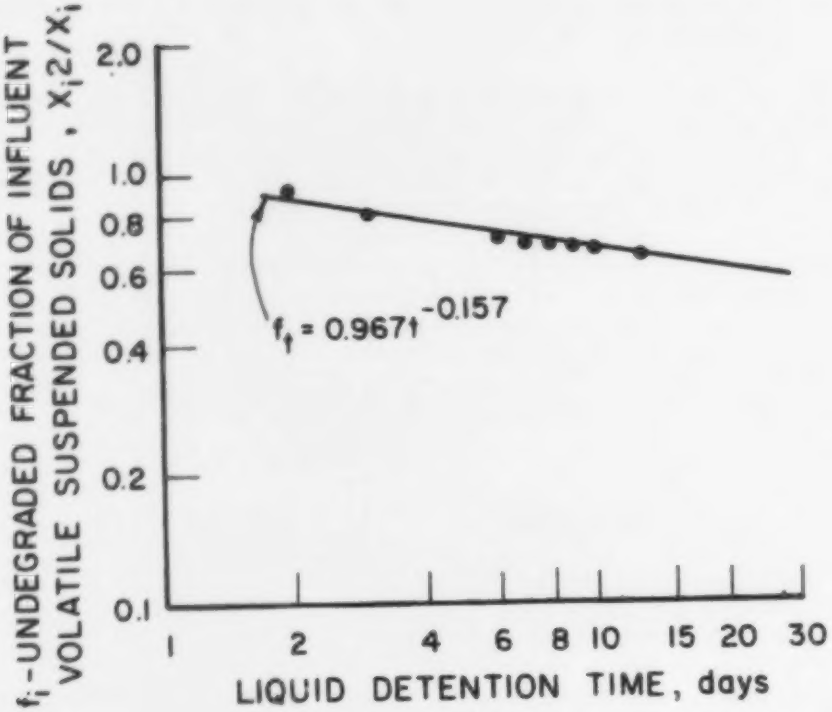


Figure 24. Residual nondegradable fraction of influent suspended solids as related to liquid detention time.

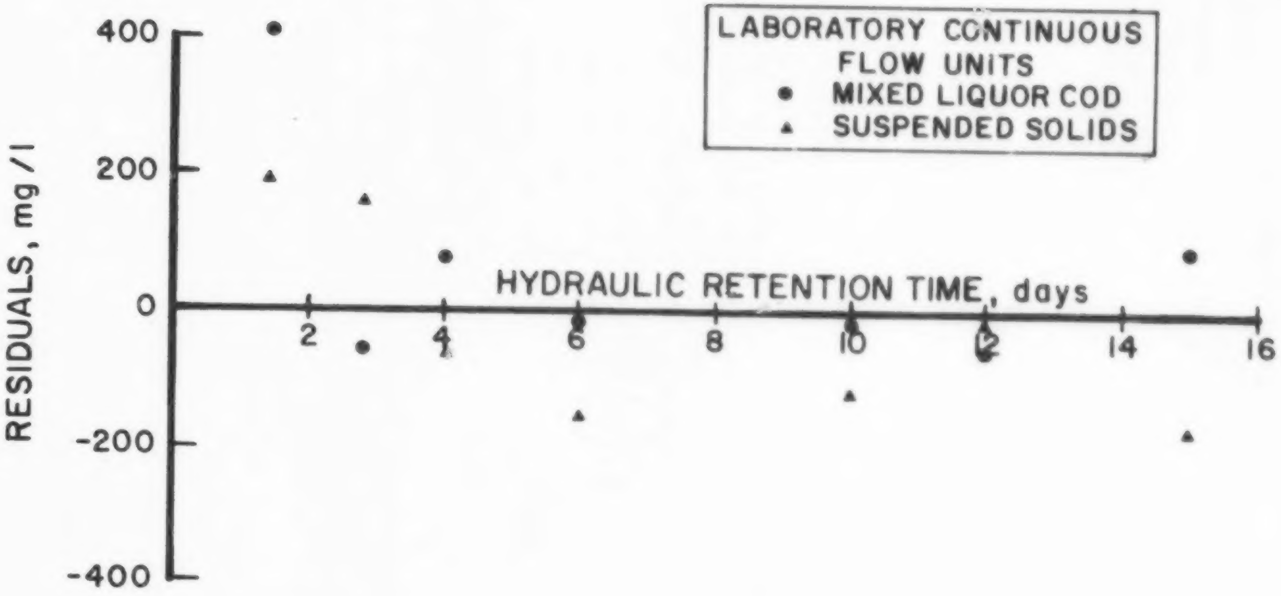


Figure 25. Residuals vs HRT (with consideration of fi).

Table 5. SOURCE OF EVALUATED CONSTANTS USED TO PREDICT EFFLUENT COD AND SUSPENDED SOLIDS

Constants	Source (Figure No.)
μm	12
Ks	12
Kd	21
Y	13
fi	24

The basic idea behind the use of residuals as a method of comparison of expected and observed residuals is that if a proposed relationship is adequate, the variations, i.e., residuals should be due solely to experimental errors. A plot of such residuals should reveal the magnitude of the errors as well as conditions under which other than experimental errors were the cause of the variation. If the relationship is adequate, a plot of residuals should indicate a reasonably narrow horizontal band around zero.

In Figure 25, Equations 42 and 45 were able to predict the results over a detention time ranging from about four to sixteen days. The Equations predicted higher than measured results at a detention time less than three days.

Eckenfelder -

The basic equations and notation for this approach were described earlier (page 24). The volatile sludge accumulation in a completely mixed, continuous flow reactor treating poultry wastes can be defined as:

Change of the MLVSS in the reactor

= Synthesis of Biomass - Autooxidation of MLVSS

$$\Delta Xv \cdot V = a(So - Se) \cdot Q - bXv \cdot X \qquad (48)$$

where $\Delta Xv = \frac{Xv}{t} = D \cdot Xv$,

$$\frac{Q}{V} = D = \frac{1}{t}, \text{ and}$$

$So - Se = Sr$, therefore

$$D = a \cdot \frac{D(So - Se)}{Xv} - b \tag{49}$$

The effluent solids is equal to ΔXv plus $fi \cdot Xo$.

Using available laboratory and pilot plant oxidation ditch data, Equation 49 was graphically evaluated to determine the values of "a" and "b", (Figures 26 and 27). The difference of "a" and "b" values (Table 6) between the laboratory and pilot plant data may be due to a) different measurements of solids concentration, i.e., suspended solids were used for the laboratory data, but total solids had to be used for the pilot plant data, and b) settled poultry manure suspensions were used for the laboratory studies while unmodified poultry wastes were used in the oxidation ditch, i.e., wastes were excreted directly into the ditch. In spite of these differences, the values of "a" and "b" were reasonably close.

The oxygen requirement can be defined as

$$\frac{Rr}{X_{SS} \text{ or } X_{TVS}} = a' \cdot \frac{D \cdot Sr}{X_{SS} \text{ or } X_{TVS}} + b' \tag{50}$$

Using the available data of laboratory and pilot plant, Equation 50 was plotted in Figure 28 and a' and b' values (Table 6) were evaluated. Again, a' and b' for the laboratory and pilot plant data are different, presumably due to the same reasons expressed for the solids data.

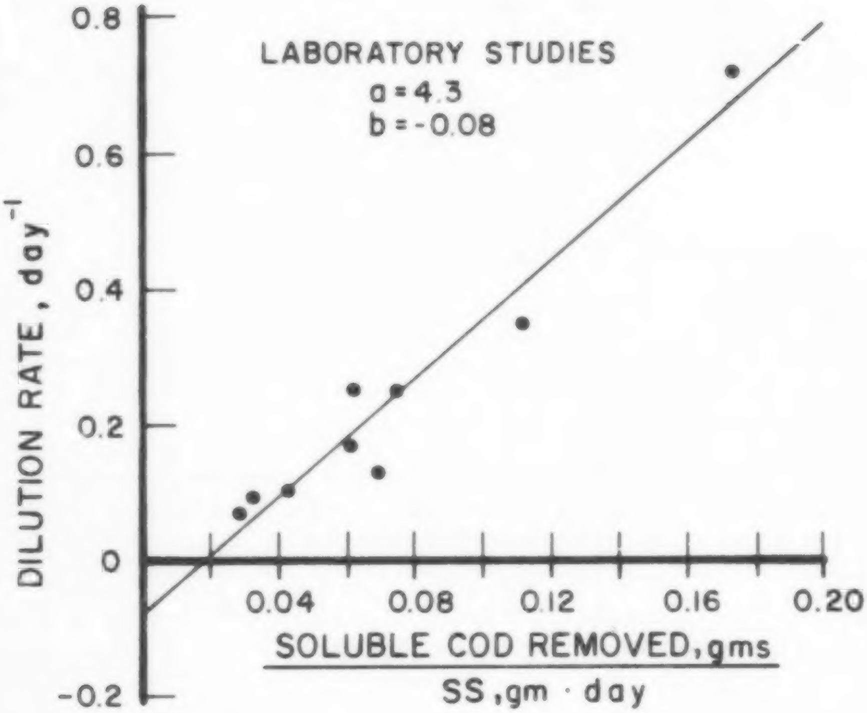


Figure 26. Graphical estimation of a and b values - laboratory data.

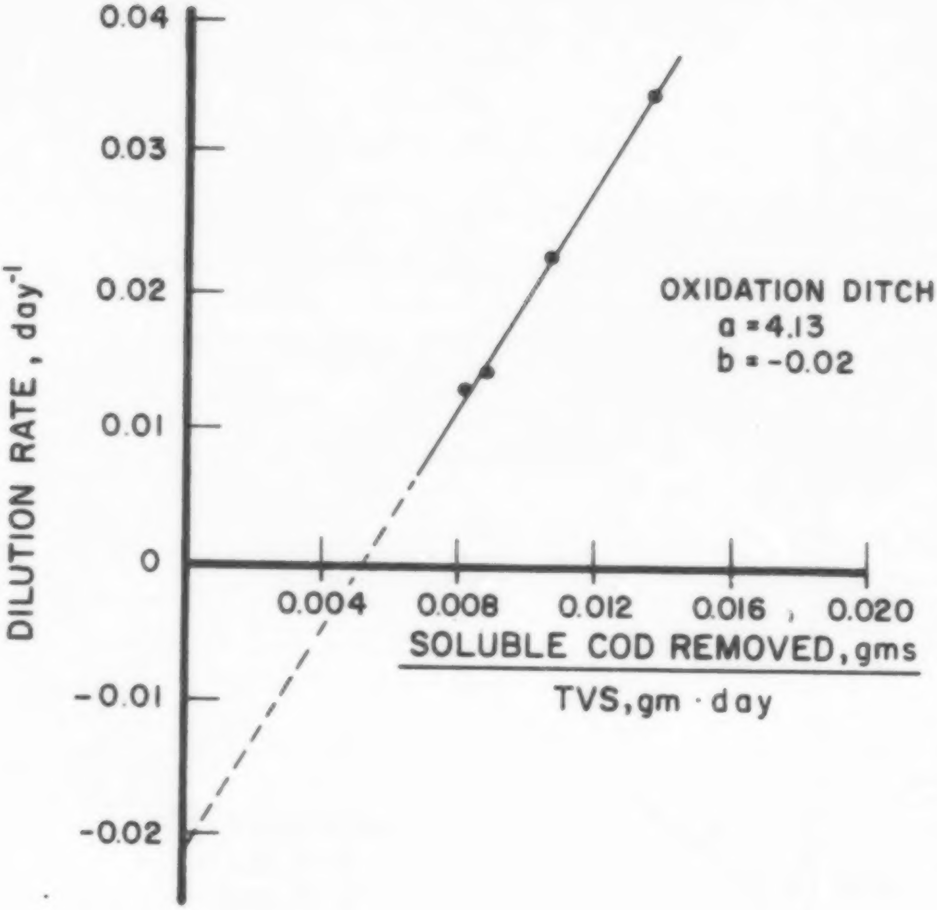


Figure 27. Estimation of a and b values using oxidation ditch data.

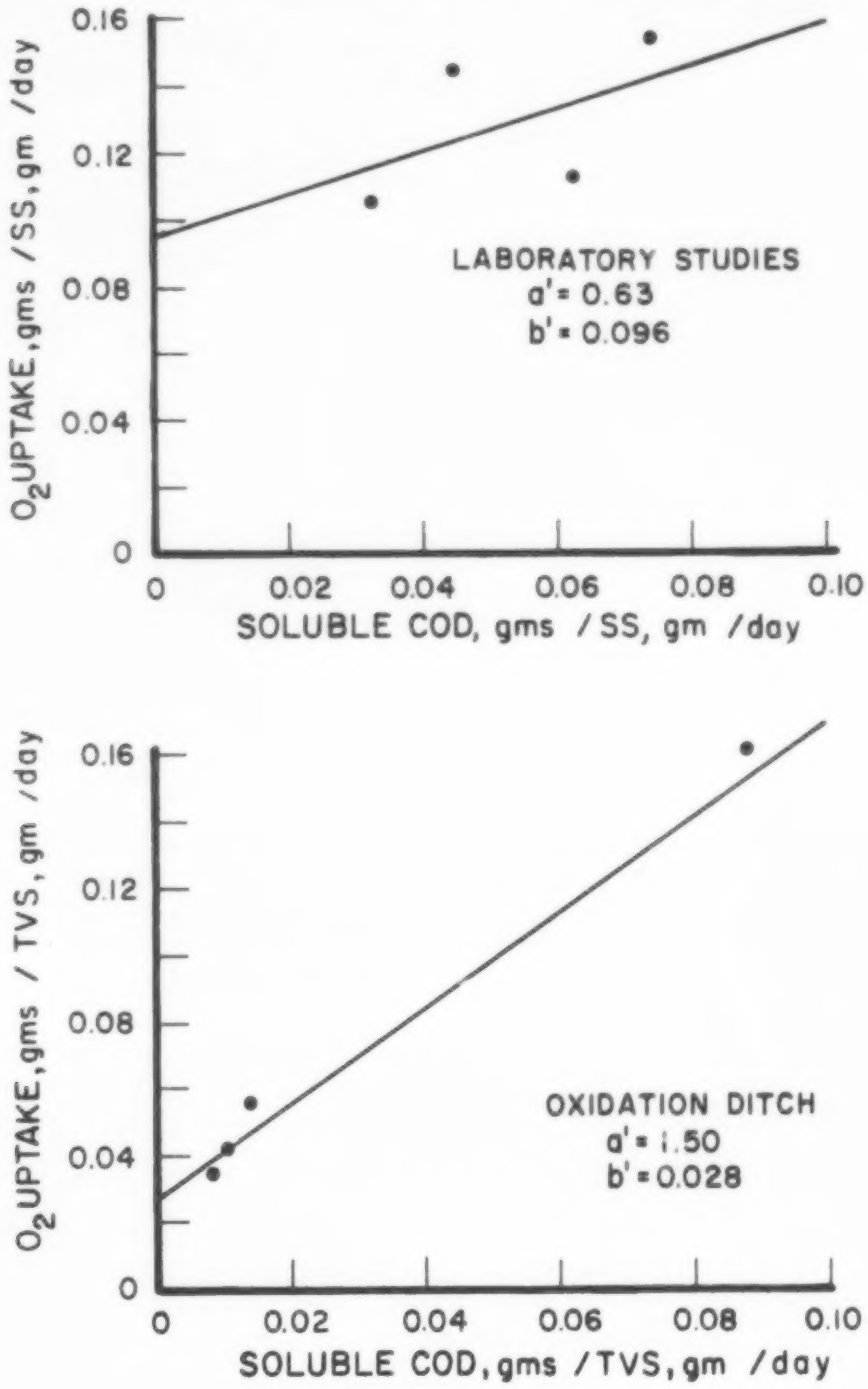


Figure 28. Estimation of a' and b' values using laboratory and oxidation ditch data.

Table 6. COMPARISON OF CONSTANTS BASED ON DATA FROM THE LABORATORY UNITS AND THE OXIDATION DITCH

Data source	a	b	Correlation coefficient	a'	b'	Correlation coefficient
Laboratory	4.30	-0.08	0.97	0.63	0.096	0.52
Oxidation ditch	4.13	-0.02	0.99	1.50	0.028	0.99

These two sets of values can be used to predict the oxygen requirements for the aerobic treatment of the respective types of poultry wastes.

The total COD in the effluent can be predicted when the soluble fraction and the COD of the solids are known.

$$Se = Se_1 + Se_2 = Se_1 + fo \cdot \Delta X_{SS} (\text{or } \Delta X_{TVS}) \tag{51}$$

where Se_1 = soluble COD in the effluent
Se_2 = insoluble COD in the effluent
fo = COD equivalent of effluent suspended solids (X_{SS}) or total volatile solids X_{TVS}, i.e., b'/b

The soluble COD in the effluent is equal to

$$Se_1 = \frac{Si_1}{K \cdot X_V \cdot t + 1} \tag{52}$$

which is comparable to Equation 19 described earlier.

Where Si_1 = soluble influent COD
K = soluble COD removal rate
X_V = MLVSS, MLTVS, or other parameter compatible to the manner by which K was determined
t = liquid detention time

The removal rate constant, K, determined from these studies, can be used for poultry manure wastewaters.

Equation 51 can be used to estimate the total COD of an effluent. Using relationships developed in this study, the predicted results are compared to the actual results in Figure 30 for laboratory data and in Table 7 for the oxidation ditch data. Data obtained by the application of McKinney's approach are also included here and these will be discussed later in the report.

The prediction of the suspended solids concentration was better than that of total COD (Figure 29). This may be because the constants for the suspended solids originated from a laboratory continuous flow unit and had a correlation coefficient of 0.95. The prediction of the mixed liquor COD was based on the sum of the soluble COD and the COD equivalent of the effluent suspended solids. Thus greater randomness of the MLCOD residuals may be reasonable.

Again, the Equations provide a reasonable fit over a detention time ranging from four to sixteen days but not as good a fit at lower detention times.

McKinney -

The basic equations and notation for this approach were described earlier (page 20). The design equations developed by McKinney (7-9) have been for the biodegradable, soluble fraction of wastewater and must be modified to include any insoluble organic matter in the influent wastewater. Since most animal wastes and wastewater contain a significant amount of insoluble or particulate materials which are partially biodegradable, the evaluation of the constants (Ks, Ke) in these equations must consider the effect of the presence of particulate materials. The present study has followed the procedures proposed by Burkhead (30) for the evaluation of CMAS constants with consideration of the particulate matter in the wastewater.

"Km" was evaluated from the soluble COD data collected from the laboratory continuous flow unit. These data were corrected for the COD of NO_2-N and the non-degradable soluble COD in the reactor. The influent soluble COD data were corrected for the non-degradable portion. The result is shown in Figure 30. "Km" can be calculated from the value of the slope of the line of best fit.

"Ks" is a function of "Km" or "K"m", where "K" is a composite coefficient that includes the energy-synthesis relationship that exists for the food being metabolized and the composition of cellular material produced. Thus "Ks" can be defined as $K_1 \cdot K_2 \cdot Km$ where K_1 is related to the energy-synthesis constant and K_2 is the reciprocal of the oxygen equivalence

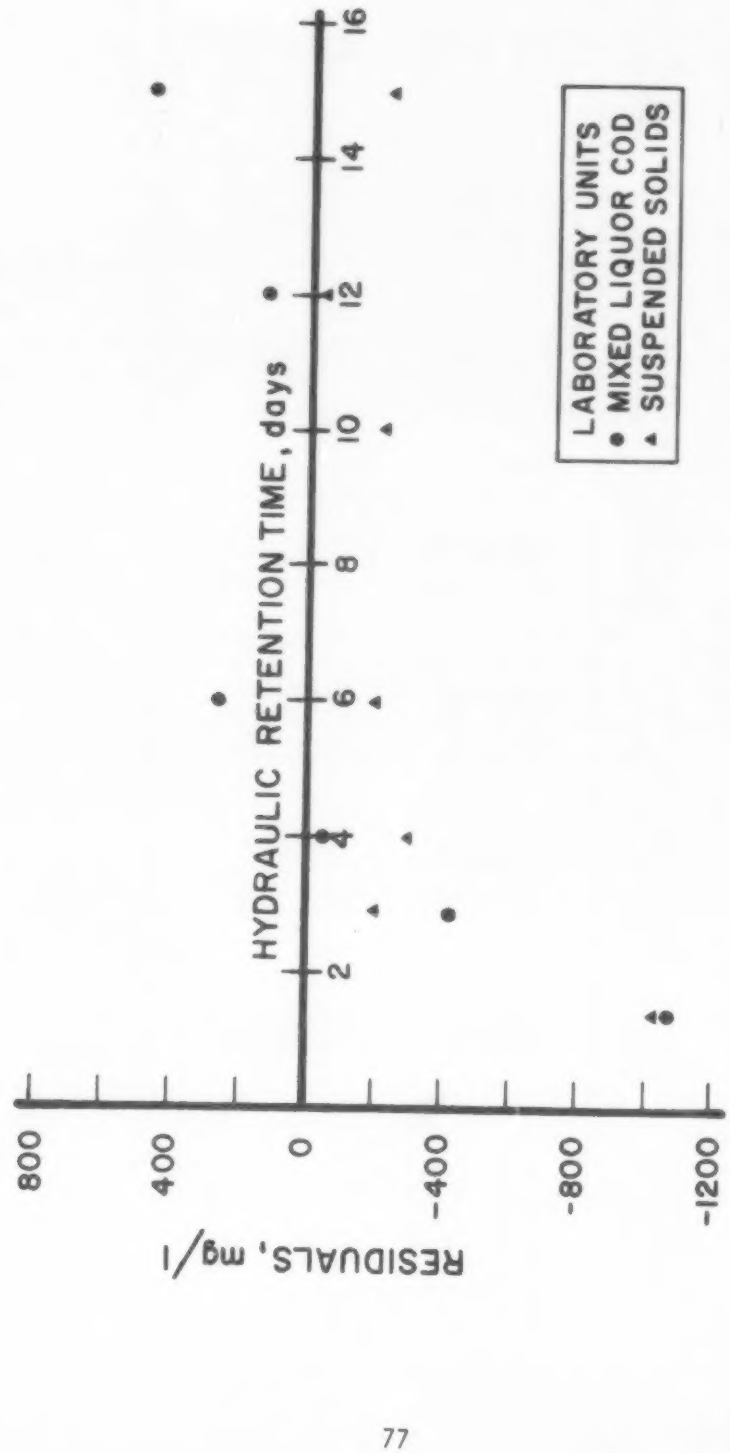


Figure 29. Relationship between residuals and HRT.

Table 7. COMPARISON[a] OF DIFFERENT DESIGN APPROACHES FOR THE AEROBIC TREATMENT OF POULTRY WASTES

Design approach	HRT (days)	Total effluent COD predicted (mg/l)	Total effluent COD measured (mg/l)	Total effluent COD predicted/measured	Effluent solids concentration predicted (mg/l)	Effluent solids concentration measured (mg/l)	Effluent solids concentration predicted/measured
					Suspended Solids		
Mass balance - this study	29	16,300	17,560	0.92	12,770	11,950	1.07
	43	21,580	22,540	0.85	17,200	16,300	1.06
	70	25,040	25,240	0.99	20,760	19,200	1.08
	77	26,270	28,800	0.91	22,080	21,000	1.05
ave.				0.92			1.06
Monod	29	16,300	17,560	0.93	14,950	11,950	1.25
	43	21,160	25,540	0.83	19,420	16,300	1.19
	70	24,350	25,240	0.97	22,350	19,200	1.16
	77	25,400	28,800	0.88	23,300	21,000	1.11
ave.				0.90			1.18

continued.

Table 7 (continued). COMPARISON[a] OF DIFFERENT DESIGN APPROACHES FOR THE AEROBIC TREATMENT OF POULTRY WASTES

		Total effluent COD			Effluent solids concentration		
Design approach	HRT (days)	predicted (mg/l)	measured (mg/l)	predicted/measured	predicted (mg/l)	measured (mg/l)	predicted/measured
					Suspended Solids		
Eckenfelder	29	15,220	17,560	0.87	10,130	11,950	0.85
	43	21,540	25,540	0.84	14,190	16,300	0.87
	70	29,320	25,240	1.16	19,050	19,200	0.99
	77	31,700	28,800	1.10	20,550	21,000	0.98
ave.				0.99			0.92
					Total Volatile Solids		
McKinney	29	14,600	17,560	0.83	11,450	16,500	0.69
	43	20,250	25,540	0.79	15,260	21,300	0.72
	70	26,760	25,240	1.06	19,460	23,500	0.83
	77	28,800	28,800	1.00	20,750	24,800	0.83
ave.				0.92			0.77

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[a] Design constants for the approaches were developed using laboratory data. The comparison was made by using these constants to predict the results that should occur in an oxidation ditch and then comparing the predicted results to those in the pilot plant oxidation ditch.

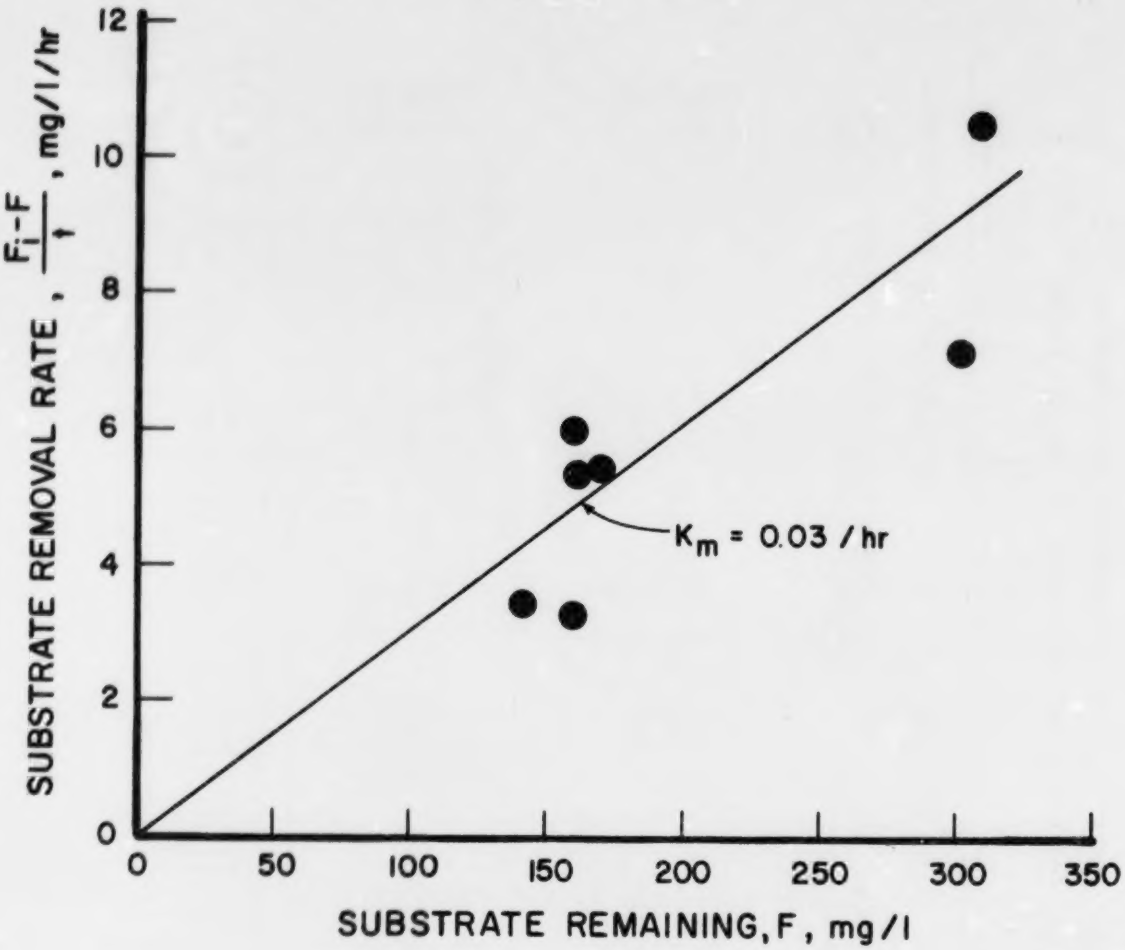


Figure 30. Graphical evaluation of Km value.

of the cellular mass synthesized. If the wastewater contained particulate material which can be partially degraded, K_1 and K_2 can be defined as (30):

$$\text{Pseudo } K_1 = \frac{\text{COD of Ma + Me}}{\text{COD Removed}}$$

$$= \frac{\text{Insoluble COD of ML - Insoluble Non-biodegradable COD}}{\text{Total COD - Unmetabolized Soluble Degradable COD - Total Non-biodegradable COD}} \qquad (53)$$

$$K_2 = \frac{\text{Ma + Me}}{\text{COD of Ma + Me}}$$

$$= \frac{M_T - \text{Mi} - \text{Mii}}{\text{COD of Ma + Me}}$$

$$= \frac{M_T - \text{Mi} - \text{Mii}}{\text{Insoluble COD of ML - Insoluble Non-biodegradable COD}} \qquad (54)$$

Based on the above definition, the K_1 and K_2 values can be evaluated from the relationship shown in Figure 31 by using the available laboratory continuous flow data. Pseudo K_1 is related to detention time while K_2 is not.

"Ke" was evaluated by the following equation (55) using data from the continuous flow laboratory units:

$$\text{Ke} = \frac{\text{Ks}\cdot\text{F} - \text{Mv/ts}}{\text{Mv} - 0.2\cdot\text{Ks}\cdot\text{F}\cdot\text{ts}} \qquad (55)$$

The values of "Ke" were obtained at different detention times. Previous studies (8, 30) have adopted a value of (0.02 hr^{-1}) to represent "Ke"

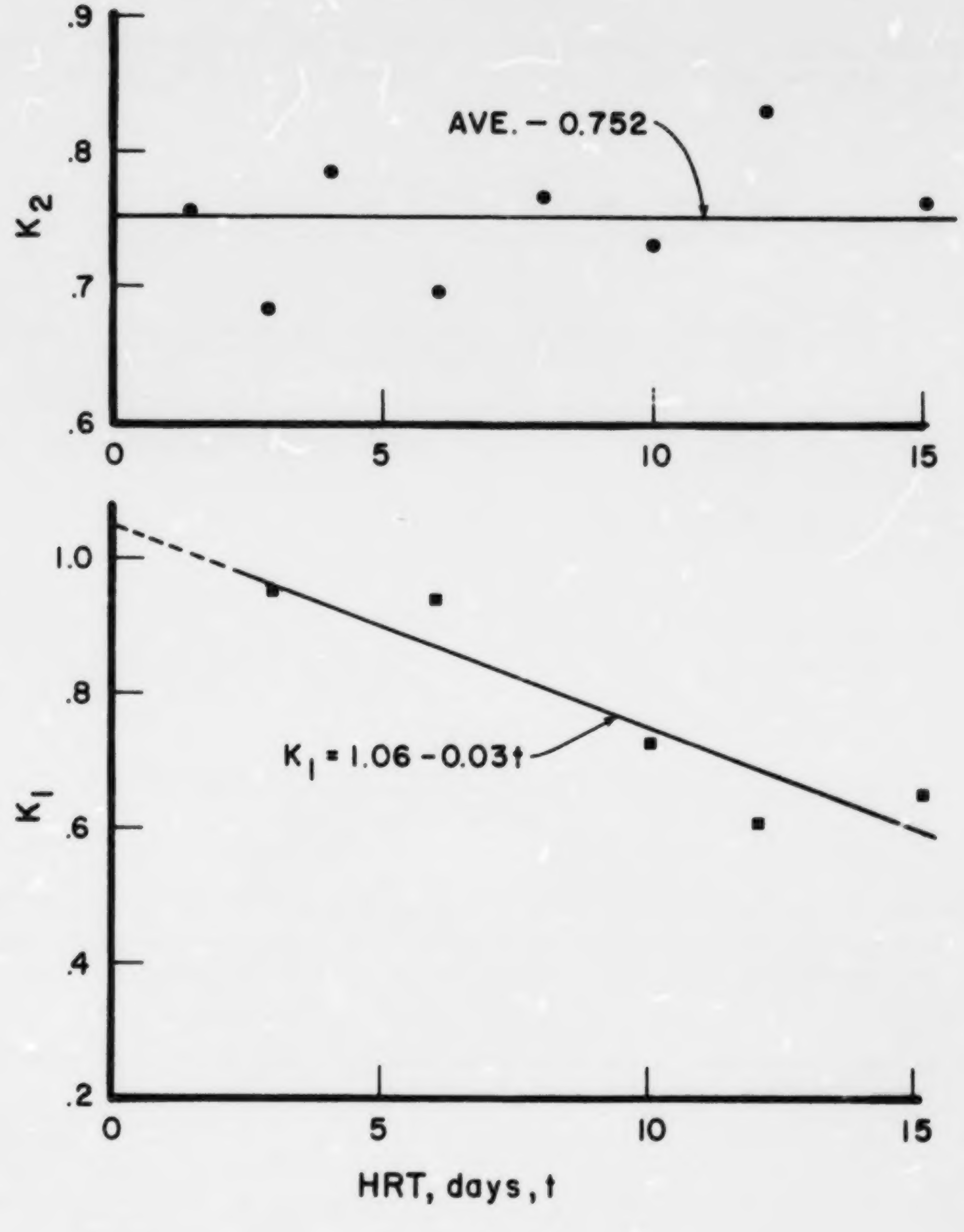


Figure 31. Estimation of K_1 and K_2 using laboratory CMAS data.

at different aeration times. In this study, the "Ke" values were compared to the organic loading rate (Figure 32) and a reasonable correlation resulted. "Ke" values lower than those previously reported were observed at low loading rates.

With some of the necessary constants evaluated, they were applied to data from the continuous laboratory units and the oxidation ditch to estimate the effluent COD and solids. The estimates obtained using the equations were then compared to the measured data. The solids concentration in the effluent was calculated as proposed by McKinney while the mixed liquor or total COD in the effluent from a system such as noted in Figure 20 was estimated as follows:

MLCOD in the effluent = [unmetabolized soluble COD]

+ [non-degradable soluble COD] + [COD equivalent of biomass in the effluent]

+ [non-degradable insoluble COD contained in the influent] (56)

where COD of biomass $= \frac{1}{K_2} \times (Ma + Me)$

$$= 1.33\ (Ma + Me) \qquad (57)$$

"fi" equaled 0.465 times the total suspended solids in the influent for the laboratory data. For the pilot plant data, "fi" was equal to:

$$1.814 \times (\text{aeration time, days})^{-0.52} \qquad (58)$$

and the non-degradable soluble COD in the influent was 0.25 times the total soluble influent COD.

The predicted and measured total COD and solids values were compared using their residuals (Figure 33). The residuals decreased as the aeration time increased. This may be due to the fact that the fraction of non-degradable suspended solids in the influent was not 0.465 and may be a function of aeration time. The residuals were more reasonable at longer detention times, greater than ten days.

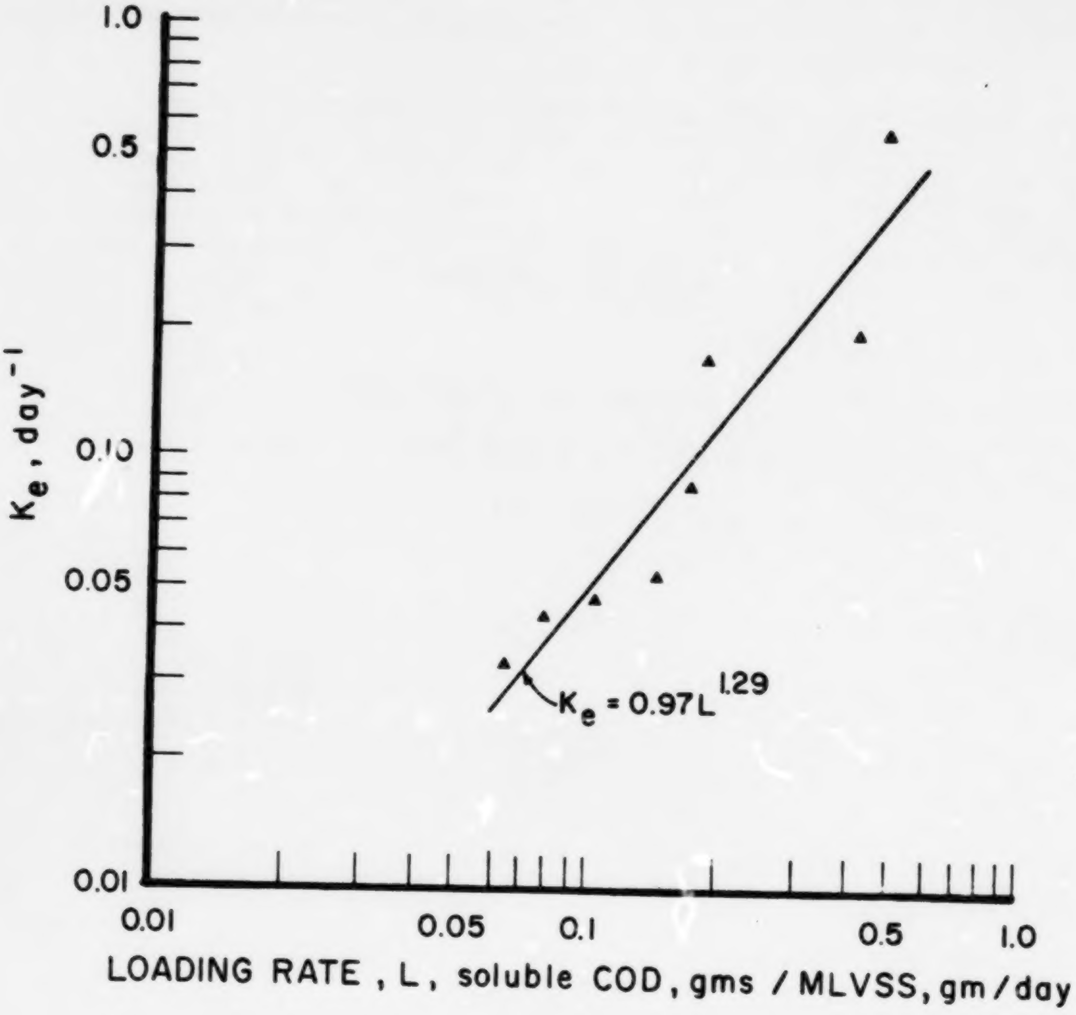


Figure 32. Ke related to soluble COD loading rate.

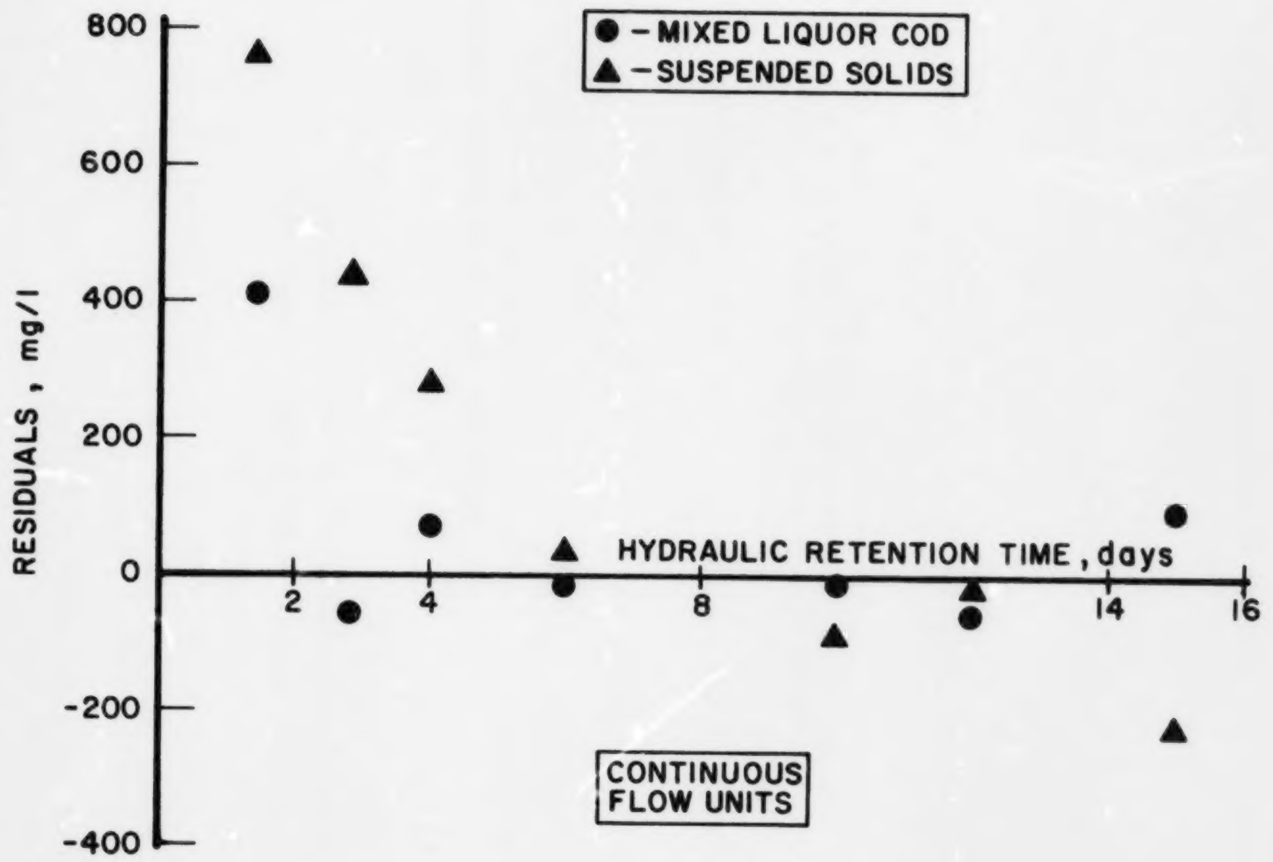


Figure 33. COD and suspended solids residuals related to hydraulic retention time - fi was not considered.

Assuming that the non-degradable fraction was a function of detention time and using the relationship noted in Figure 28 did not increase the ability of the equations to predict actual values (Figure 34). The residuals were even greater than before.

The following equation was proposed by McKinney to predict the oxygen uptake rate:

$$\frac{do}{dt} = \frac{1.5(Fi - F)}{t} - \frac{1.42(Ma + Me)}{ts} \tag{59}$$

Equation 59 estimates the oxygen requirement for the soluble substrate and does not consider the oxidation of the insoluble substrate present in the influent or the oxidation of NH_4-N to NO_2-N or/and NO_3-N.

In the aerobic treatment of a waste as complex as poultry manure, both the oxidation of the insoluble components and the oxidation of the nitrogen should be considered when determining the oxygen requirements of the aerobic unit.

Accordingly, Equation 59 was modified as follows to incorporate these factors:

$$\frac{dO}{dt} = \frac{1}{t}[Si_{11} - \bar{S}_{11} - 1.42X_{11} + Si_2(1 - f') + O_2 \text{ needed for nitrogenous oxygen demand}] \tag{60}$$

where Si_{11} = soluble degradable COD in the influent, mg/l

$\bar{S}_{11}$ = soluble degradable COD in the effluent, mg/l

X_{11} = biomass concentration, mg/l

Si_2 = insoluble COD in the influent, mg/l

f' = undegradable fraction of insoluble COD at an aeration time, t (days)

For these experiments, f' was equal to $0.87 \times t^{-0.28}$. Equation 60 was applied to the oxidation ditch data (Table 8).

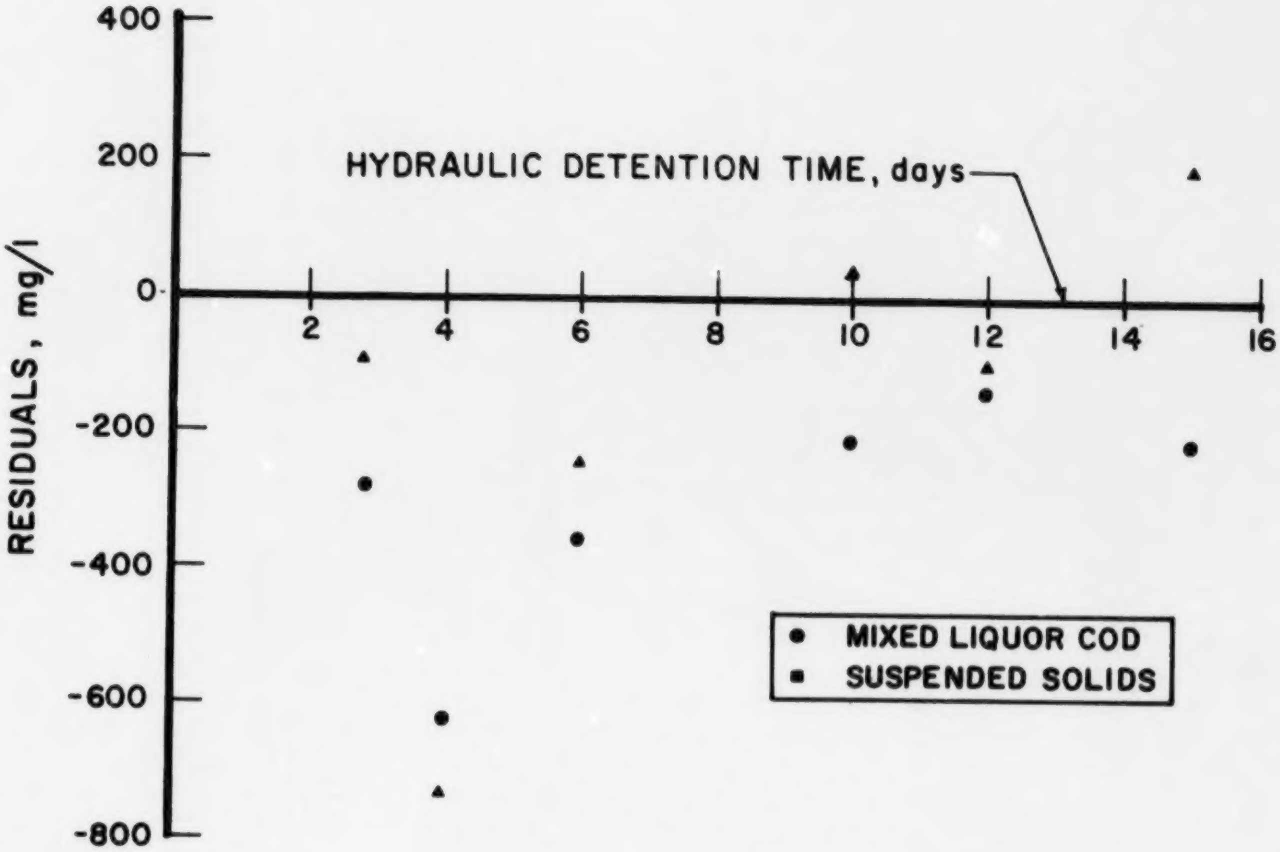


Figure 34. COD and suspended solids residuals compared to HRT - fi was considered.

Table 8. COMPARISON OF O_2 UPTAKE RATE BY THE MODIFIED McKINNEY'S APPROACH

HRT (days)	O_2 uptake rate (mg/l/hr) (predicted)	O_2 uptake rate (mg/l/hr) (measured)	$\frac{\text{Predicted}}{\text{Measured}}$
29	32.7	39.3	0.83
43	34.0	37.3	0.91
70	30.3	40.5	0.75
77	31.3	34.8	0.90

The results indicate that Equation 60 can be used to estimate the oxygen uptake rate of aerobic systems treating poultry wastes.

Summary

All of the approaches evaluated appeared to be able to predict the effluent characteristics of an operating aerobic poultry waste treatment system (oxidation ditch) reasonably well. The key to the success of the approaches lies in being able to evaluate the constants necessary to each approach. The constants were developed independently using the results of laboratory studies and were applied to an operating oxidation ditch. It is interesting to note that the constants developed from the laboratory data were able to be used to adequately predict the performance from a larger scale operating unit, especially since some of the waste characteristics, operating conditions, and measurements of some of the parameters were different.

A summary comparison of all of the design approaches that were studied was presented in Table 7. All of the approaches were able to predict the actual effluent characteristics, generally within about 10-15%. This variation is not bad considering the variations that took place in the laboratory units and the oxidation ditch. The variation is tolerable enough that any of the approaches can be used for general predictive purposes and possibly for actual design purposes.

Some of the approaches had wider variations over the detention times used for comparison than did other approaches. The choice of which approach should be used will depend upon the ease with which the respective constants can be obtained and verified and upon the experience of the design engineer with a particular approach.

The oxygen requirements of the laboratory units and the oxidation ditch could not be directly compared because different parameters of active mass were used in each case. Representative oxygen demand requirements that can be used for design purposes are noted in the report.

DESIGN EXAMPLE

The following section deals with approaches for designing a treatment system for poultry wastes to accomplish COD and suspended solids removal and odor control. Poultry wastes and wastewaters are very concentrated and are disposed of on land adjacent to poultry farms. Therefore, certain basic constraints exist in developing the design of a feasible treatment system for these wastes. These constraints are: 1) land will be the ultimate disposal medium rather than surface water bodies, 2) primary treatment, i.e., separation of solids prior to biological treatment, is an unnecessary part of a poultry waste treatment system and will not be used, and 3) treatment to a level to achieve the EPA set guidelines for effluent COD and suspended solids is not necessary. It is impractical to attain the secondary effluent guidelines with these wastes unless the wastes are diluted either before or after treatment, water carriage systems are used, and large unit operations are provided.

The two design approaches presented here include one to show the futility of designing treatment systems to attain the EPA quality for secondary effluents, and one utilizing the mass balance approach developed in this study for predicting suspended solids and COD concentration in the effluent.

An oxidation ditch without solids recycling is considered as the basic treatment device in these approaches because of the following considerations: a) it can be used directly under the cages to receive and treat the wastes without any unit operations ahead of it, b) it can aerobically stabilize wastes and provide simultaneous odor control, c) it can be installed and operated with considerably less degree of sophistication than alternative aerobic treatment systems, and d) it can be constructed indoors and operated without being affected severely by seasonal temperature fluctuations.

Approach I

Objective -

Designing a system to treat poultry waste to attain the EPA guidelines for domestic wastes for effluent BOD_5 and suspended solids, i.e., 30 mg/l and 45 mg/l respectively.

Assumptions -

1. Number of birds: 10,000
2. COD/bird/day - 0.0430# (19.5 g)
3. SS/bird/day = 0.024# (10.98 g); Total Solids/bird/day = .068#(21.8 g)
4. Loading rate = 1 lb COD/1 lb of MLVSS (1 kg COD/1 kg MLVSS)
5. No primary settling will be needed
6. No secondary settling will be needed
7. 1 mg/l BOD_5 = 2 mg/l of COD

Using the mass balance approach developed in this study, the influent COD required to accomplish a COD of 60 mg/l in the effluent may be computed for various HRT values.

$$K = \frac{Si - \bar{S}}{\bar{S} \cdot t}$$

where $K = 0.128 \text{ day}^{-1}$
Si = influent COD
$\bar{S}$ = effluent COD

The computed influent COD concentrations, the volume of dilution water needed to attain this influent COD concentration, and the volume of ditch to provide the needed HRT are given in Table 9.

The corresponding influent suspended solids concentration at the dilution water used (Table 9) were computed assuming that the suspended solids contribution/bird/day was 0.024 lbs. This influent suspended solids concentration was used to predict the effluent suspended solids concentration by applying the mass equation developed in our study. ($k' = Xi - \bar{x}/t \cdot \bar{x}$; $k' = 0.161 \text{ days}^{-1}$; Xi = influent suspended solids concentration; $\bar{x}$ = effluent suspended solids concentration; and t = detention time, days). These design computations are given in Table 10.

Since the expected effluent suspended solids concentration at the various HRT values is less than the guidelines set by EPA, the design parameters

Table 9. INFLUENT COD CONCENTRATION, HRT, AND VOLUME OF DITCH NEEDED TO YIELD THE SECONDARY EFFLUENT CRITERION FOR COD (60 mg/1)

HRT (days)	Influent COD, mg/1	Volume of dilution water required to attain the influent COD concentration liters x 10^6	Capacity of the oxidation ditch, liters x 10^6	Volume of oxidation ditch/bird, liters
5	98	1.990	9.95	995
10	137	1.423	14.237	1423
20	214	.911	18.229	1822
30	290	.672	20.177	2018
40	367	.531	21.259	2125
50	445	.438	21.916	2191
60	520	.375	22.505	2250
70	597	.326	22.87	2287
80	674	.289	23.151	2315
90	750	.260	23.406	2340

Table 10. RELATIONSHIP BETWEEN HRT, INFLUENT SUSPENDED SOLIDS CONCENTRATION, AND EXPECTED EFFLUENT SUSPENDED SOLIDS CONCENTRATION

HRT (days)	Resultant influent suspended solids concentration [a] mg/l	Expected effluent suspended solids concentration mg/l
5	55	30.4
10	76	29
20	119	28
30	162	27.8
40	205	27.5
50	248	27.4
60	290	27.2
70	333	27.1
80	376	27
90	419	27

[a] This suspended solids concentration was achieved by diluting the waste with the quantities of water mentioned in Table 9.

used for achieving the effluent COD criterion (60 mg/l) should automatically yield an effluent suspended solids concentration that conforms to the EPA guidelines.

Using the equation developed in this report, the influent suspended solids concentration was computed at various HRT's that are required to achieve the effluent suspended solids concentration of 45 mg/l set by EPA (Table 11). The amount of dilution water necessary to achieve this suspended solids concentration from the suspended solids excreted by the 10,000 birds is also given in Table 11.

Even though these considerations (Table 11) show that it is possible to design a system for achieving the EPA secondary effluent guidelines, such an approach is not practically feasible because of the following considerations.

1) EPA guidelines do not permit discharge of wastes from agricultural operations to surface waters, and thus it is not necessary to strive for these guidelines when land is considered as the ultimate disposal medium.

2) Parenthetically, even if EPA would allow the discharge of wastes from agricultural operations, enormous size aeration units and large quantities of water are needed to achieve the desired effluent criteria. The cost of water required for dilution of the large size treatment units required, the operating costs, and the need to dispose of water used only for dilution, do not justify using this approach. Alternative approaches are more feasible.

3) Even if the effluent COD and suspended solids criteria are satisfied by this approach, the concentration of nutrients such as N and P contained in the effluents will be greater than the limits known to cause eutrophication.

Approach II

In this approach no effort is made to achieve the secondary effluent criteria for domestic wastes since it is impractical to dilute the waste first and treat it, or treat it first and dilute it later for discharge into surface waters, an alternative approach is made to design the systems to treat the concentrated waste and dispose of the relatively concentrated effluent on land.

One of the design criteria considered in this approach was to have the ditch operated at a total solids concentration of less than 2%. Above this solids concentration, oxygen transfer was shown to be impaired (43).

Table 11. RELATIONSHIP BETWEEN HRT AND INFLUENT AND SUSPENDED SOLIDS TO ACHIEVE AN EFFLUENT SUSPENDED SOLIDS CONCENTRATION OF 45 mg/1

HRT (days)	Influent SS concentration (mg/1)	Dilution water needed to achieve the influent suspended solids (liters x 10^6)	Volume of ditch needed, (liters x 10^6)	Volume of ditch/bird (liters)
5	81	1.344	6.72	672
10	117	.930	9.304	930
20	190	.572	11.459	1145
30	262	.415	12.465	1246
40	335	.325	12.998	1300
50	407	.267	13.374	1337
60	480	.227	13.608	1360
70	552	.197	13.805	1380
80	625	.174	13.934	1393
90	697	.156	14.057	1405

The size of the ditch needed to give the effective solids concentration 1% at various detention times can be computed using the equations developed in this study.

Assumptions -

(1) 2 x Suspended Solids = TS in raw waste

(2) 3 x Suspended Solids = TS in stabilized waste

(3) Assume waste is considered stabilized for design purposes beyond a 10 day HRT

(4) 240# of SS are produced/day

(5) Other assumptions are the same as in Approach I.

Using the equation

$$K = \frac{X - \bar{x}}{\bar{x} \cdot t}; \quad K = 0.161 \text{ at 1 gm of COD/1 gm of MLVSS loading}$$

at HRT 10 days,

$$= .161 = \frac{240 - \bar{x}}{10 \cdot \bar{x}}; \quad \bar{x} = 91.95\text{\# SS remaining}$$

$$= 91.95 \times 3 = 275.85\text{\# of TS remaining}$$

To have a 1% slurry means

$$275.85 \text{ lbs} \times 453.6 \frac{\text{g}}{\text{lb}} \times \frac{100 \text{ ml}}{1000 \text{ ml}} = 12512 \text{ liters of slurry}$$

i.e., the quantity of manure added daily to the ditch should be diluted to 12512 liters in order to obtain the same volume of effluent from the ditch. At an HRT of 10 days, the ditch capacity would be 12512 liters x 10 = 125120 liters.

Similarly, in order to achieve a 1% solids concentration in the effluent at an HRT of 20 days, the volume of effluent to be withdrawn per day would be 7756 liters. This means that the manure added to the ditch daily should be made up to 7756 liters to maintain the equilibrium liquid volume. Thus at 20 days HRT, the ditch volume would be 7756 x 20 = 155,120 liters.

It should be noted that in addition to the water added with the input manure, additional water may be required to compensate the losses due to evaporation in order to maintain the equilibrium liquid volume.

The foregoing should only be considered as an example showing the application of the equations developed in this study. For predicting the effluent quality from a treatment system using these equations, the loading factor should first be ascertained. This will enable the determination of K' and K from equations 34 and 37. These values can then be used in conjunction with the actual detention time of the system to predict the concentration of COD and SS in the effluent. The values of K' and K used in the above example were meant for a loading factor of 1 and may not be typical of actual systems. (See Conclusions Section of the report also.)

Volume of Water Needed to Maintain the Liquid Depth in the Oxidation Ditch

In order to maintain a constant liquid depth in the ditch, the volume of the material (manure + water) entering into the ditch should be equal to the volume of effluent withdrawn. Thus for a 10 day HRT, the volume of the manure entering daily into the ditch should be made up to 12512 liters by adding water. Assuming the 480 lbs (218 kg) of total solids entering the ditch will have a wet weight of 1920 lbs (872 kg) and will occupy a volume of 230.5 gallons (872 liters), 11,640 liters of water for making up the volume to 12, 512 liters will be needed.

COD Concentration in the Effluent

Assume

a) HRT = 10 days

b) influent COD = 430 lbs (195.45 kg)/day

c) k = 0.128 (loading rate, 1 gm COD/ 1 gm of MLVSS)

Using the equations developed in this study

$$0.128 = \frac{430 - \bar{s}}{\bar{s} \cdot 10}$$

$$\bar{s} = 188.5 \text{ lbs } (85.7 \text{ kg})$$

The effluent COD of 188.5 lbs will be contained in the 12,512 liters of effluent that will be withdrawn per day. At this HRT the COD effluent will be

$$\frac{188.5 \times 453.6 \times 1000}{12{,}512} = 6834 \text{ mg/l}$$

Oxygen Requirements

The computation of oxygen requirements is made with and without considering the nitrogenous oxygen demand of the poultry waste. The former consideration is applicable for situations where minimal aeration is practiced and no nitrification is contemplated while the latter is applicable to situations where nitrification of the waste is desired.

To accomplish the transfer of oxygen, a rotor made by Thrive Centers or an equivalent rotor was assumed and oxygen transfer relationships accomplished by such rotors were utilized. In order to find the rotor length required to transfer the desired amount of oxygen at various immersion depths, the following assumptions were made

1) only one-half of COD is biodegradable and consumes oxygen

2) the performance characteristics of rotors are similar to those determined in our pilot plant studies (43)

3) 80% of the TKN is able to be nitrified

4) 1 mg of NH_4-N requires 4.6 mg oxygen for conversion to NO_3.

Case I: Oxygen Requirements with No Nitrification

Assuming the daily COD input from the birds as 430 lbs (195·5 kg), the oxygen demand due to the biodegradable fraction will be 215 lbs (97.7 kg)/day.

Two hundred fifteen lbs of oxygen per day (8.96 lbs/hr) should be supplied. This assumes no residual dissolved oxygen in the mixed liquor and represents the minimum amount of oxygen that must be supplied by a rotor. If a residual dissolved oxygen concentration is desired, the amount of oxygen necessary to achieve that concentration, and the possibility of nitrification needs to be considered.

Case II: Oxygen Requirements with Nitrification

i) O_2 required for biodegradable fraction: 215 lbs/day

ii) O_2 required for nitrogenous demand:

TKN (lb/bird/day) = 0.0018
(Higher TKN contribution per bird is possible, and it should be determined prior to the computation of O_2 requirements for nitrification.)
. TKN of 10,000 birds = 18 lbs/day

a) Assuming 80% of this is able to be nitrified, 18 x 0.8 or 14.4 lbs of nitrifiable N/day will result.

b) This will have a nitrogenous oxygen demand of 14.4 x 4.6 or 66 lbs O_2/day, assuming up to the NO_3^- stage

iii) Total O_2 demand = 215 + 66 = 281 lb/day or ≈ 12 lb/hr.

iv) The dissolved oxygen to be maintained in the ditch is 2 mg/l; the ditch volume is 125,120 liters at a 10 day HRT. This dissolved oxygen concentration is chosen as the minimum dissolved oxygen concentration to be maintained at all times for sustaining nitrification.

At the above D.O. concentration, the O_2 transfer rate, i.e., $\#O_2$ transferred/hr can be computed as follows for the experimental pilot plant at 2 inch immersion depth having a volume of 6091 liters or containing a weight of 13,405 lbs of liquid.

$$\frac{\#O_2 \text{ transferred}}{\text{hr}} = \frac{KL_a(\text{min}^{-1})\cdot(Cs - CL)\cdot \text{lbs of water} \times 60\ \frac{\text{min}}{\text{hr}}}{10^6}$$

Assuming a KL_a value of 0.166 at 2 inch immersion depth, at 20°C and at 2 mg of equilibrium D.O. (43), this will be . .

Table 12. TRANSFER OF OXYGEN BY AN EXPERIMENTAL ROTOR AT VARIOUS EQUILIBRIUM D.O. CONCENTRATIONS*

Equilibrium D.O., mg/l	# O_2 transferred/ft/hr*
2	0.524 (7.89 gm/cm/hr)
3	0.452 (6.7 ")
4	0.379 (5.6 ")
5	0.306 (4.6 ")
6	0.233 (3.5 ")

*The immersion depth was 2 inches and the liquid volume was 6091 liters.

Table 13. ROTOR LENGTH NEEDED FOR OXYGENATION OF POULTRY WASTE FROM 10,000 BIRDS BASED ON THE PERFORMANCE CHARACTERISTICS OF A ROTOR TESTED AT AWML

Immersion depth (inches)	Total solids (% w/v)	Lbs. of O_2 transferred/hr/ft		Length of rotor needed (ft)	
		at 2.0 mg D.O./1	at 0.0 mg D.O./1	with nitrification*Δ	without nitrification†
2" (5.1 cm)	1 - 2	0.52	0.67	22.9 (7.0 m)	13.3 (4.1 m)
	3	0.42	0.54	28.3 (8.6 m)	16.5 (5.1 m)
	4	0.34	0.44	35.2 (10.7 m)	20.5 (6.3 m)
	5	0.26	0.34	45.8 (14 m)	26.7 (8.2 m)
4" (10.2 cm)	1 - 2	1.23	1.57	9.8 (3.0 m)	5.7 (1.8 m)
	3	1.0	1.27	12.0 (3.7 m)	7.0 (2.2 m)
	4	0.8	1.02	15.0 (4.6 m)	8.8 (2.7 m)
	5	0.62	0.79	19.4 (5.9 m)	11.4 (3.5 m)
6" (15.2 cm)	1 - 2	1.64	2.23	7.3 (2.2 m)	4.0 (1.3 m)
	3	1.33	1.81	9.1 (2.8 m)	5.0 (1.6 m)
	4	1.07	1.45	11.2 (3.4 m)	6.2 (1.9 m)
	5	0.82	1.12	14.6 (4.5 m)	8.0 (2.5 m)

*These values are computed assuming an equilibrium D.O. of 2 mg/l.

†These values are computed assuming an equilibrium D.O. of 0 mg/l.

ΔThese computations were based on the assumption that the contribution of TKN per bird was 0.0018 lbs/day. In computing the rotor length needed for other cases, however, the TKN contribution per bird should first be determined and then the necessary calculations should be made as presented under case II.

Table 14. DESIGN PARAMETERS AND EXPECTED PERFORMANCE OF AN OXIDATION DITCH FOR 10,000 BIRDS, AT 2" IMMERSION DEPTH

	HRT (days)	
	10	20
Oxygen required (#/day)		
nitrification	281	281
no nitrification	215	215
Estimated rotor length (ft)		
nitrification	23	23
no nitrification	14	14
Mixed liquor effluent		
Total Solids, mg/l	≈10,000	≈10,000
Suspended Solids, mg/l	≈ 5,000	≈ 5,000
COD, mg/l	6,835	7,060
Volume of effluent or overflow, liters	12,512	7,756
Volume of ditch, liters	125,120	155,120

$$\frac{0.166 \times (9.2 - 2) \times 13{,}405 \times 60}{10^6} = 0.96 \text{ lbs of } O_2\text{/hr}$$

Since the experimental rotor length was 1.83 ft, the $\#O_2$ transferred/ft of rotor length will be

$$\frac{0.96}{1.83} = 0.523 \text{ lbs/ft/hr}$$

Similarly, at other equilibrium D.O. concentrations, the $\#O_2$ transferred/ft/hr were computed and presented in Table 12.

Based on the O_2 transfer rates (Table 12) and other performance characteristics obtained for the experimental rotor in our pilot studies (43), the rotor length needed for oxygenation of the poultry waste from the 10,000 birds under consideration is computed for various immersion depths of the rotor at various solids concentration with and without considering the nitrification of the waste. The immersion depths of 2 inches, 4 inches, and 6 inches for the rotor were considered in computing the various quantities indicated in Table 13.

Similar computations can be made for other values of HRT and equilibrium D.O. concentrations in the mixed liquor. Table 14 shows summary design computations for an oxidation ditch treating waste from a 10,000 bird operation considering an equilibrium D.O. concentration of 2 mg/l for sustaining nitrification, with an HRT of 10 and 20 days.

Solids Accumulation in a Continuously Filling Reactor With No Intentional Wastage of Solids

An equation was derived to predict the concentration of total solids at any time in a continuously filling reactor. At times the oxidation ditches may be operated as a continuously filled storage and treatment device. By using the following equation, the total solids and COD concentration at any given time in the mixed liquor can be predicted.

$$Ct = Ci \cdot f \left[\frac{1+10^{-k(t+1)}}{1-10^{-k}}\right] + Ci(1-f)t$$

where
Ct = Total Solids content after time "t" (days)
Ci = influent solids contribution, gm/l/day
f = fraction of degradable solids
(1-f) = fraction of non-degradable solids
k = rate constant, reciprocal days

See the derivation and application of this equation in the Appendix A-I.

SECTION V

NITROGEN REMOVAL DURING AEROBIC WASTE TREATMENT

INTRODUCTION

The nitrogen content of poultry wastes produced in the United States in 1970 was about 9×10^6 pounds per day. Estimates of the amount of nitrogen reaching the surface or ground waters from this source are not available. With the growing concern for maintenance of our waters, greater emphasis is being placed on nutrient control with all wastes and the technical and economic feasibility of nitrogen control of animal wastes during aerobic stabilization requires investigation.

Several methods have been suggested for nitrogen removal from animal wastes. These methods can be classified as either physiochemical or biological. The biological processes of nitrification followed by denitrification has been successfully demonstrated as a possible means of elimination of nitrogen from municipal wastes. An earlier investigation conducted by the investigators of this project indicated that this process may be applicable for nitrogen control in animal waste management systems.

The results of the previous EPA study (38) have been extended in this study to obtain more information on the fundamental factors affecting nitrogen control in aerobic systems. The fundamental factors included oxygen input as related to oxygen demand, solids concentration, and nitrifying activity. In addition, nitrogen losses under operating conditions were monitored in pilot and full scale aerobic systems treating poultry wastes. These systems were oxidation ditches treating the wastes from 250 birds at the Agricultural Waste Management Laboratory and the wastes from 15,000 birds at the Houghton Poultry Farm.

MATERIALS AND METHODS

Laboratory Studies

General -

A series of laboratory studies were conducted to obtain detailed information on the factors affecting nitrogen control in aerobic systems. Details of the equipment, approaches, and methods used in these studies are outlined in this section.

Wastes -

The required concentrations of the wastes were made by suspending the requisite amount of poultry manure in distilled water. The mixture was blended in a Waring blender and filtered through a single layer of cheesecloth to remove large particulate matter. The material retained on the cheesecloth was washed with distilled water to recover most of the soluble matter. The filtered suspensions were diluted to the required volume with distilled water.

Mineral Salts Solution -

A mineral salts solution was used in certain experiments to resuspend centrifuged mixed liquor solids. The salt solution contained the following: $MgSO_4.7H_2O$, 250 mg/l; $FeSO_4.7H_2O$, 10 mg/l; $CaCl_2.2H_2O$, 10 mg/l.

Oxidation Ditch Liquor -

Mixed liquor from the pilot plant oxidation ditch was used in some laboratory experiments and is referred to in this report as ODML.

Methods -

Total solids, volatile solids, and BOD were determined as described in _Standard Methods_ (35). COD was determined by a rapid method (36).

Suspended solids were determined by filtering a known volume of the sample through glass filter paper. The weight of the dry solids retained on the filter paper was used as an estimate of the suspended solids. A considerable length of time was generally taken for the filtration of the relatively concentrated samples. In such situations, a part of the weight of the suspended solids may have included some dissolved solids.

The pH of the sample was measured with a Corning pH meter.

Ammonium nitrogen was determined by the distillation method (39). The sample was buffered with phosphate buffer to pH 7.4 and was distilled in a micro-Kjeldahl distillation apparatus. The distillate was collected in boric acid and titrated with $KH(IO_3)_2$.

Total Kjeldahl nitrogen was determined by a micro-Kjeldahl method (39).

Nitrite nitrogen was determined by a diazotization method using N-1-napthyl ethylene diamine dihydrochloride (39).

Nitrate nitrogen was determined by the PDSA method as described in Standard Methods (35) but with some modification (39). Clarification of the sample with $Al(OH)_3$ was omitted. Clarification was achieved by a very high sample dilution which was found to be necessary to obtain the range of NO_3-N suitable for determinations. NO_2-N in the sample was eliminated after the chlorides were removed. A neutral aliquot of the diluted sample was adjusted to pH 2 by the addition of sulfamic acid crystals. In some of the samples, nitrate was determined by the distillation procedure (39).

Storage of Samples -

All the nitrogen analyses, COD, and BOD were performed on the samples rapidly and without storage. NO_2-N and NO_3-N analyses of samples stored with H_2SO_4 were found to be unsatisfactory. In the determination of solids, it sometimes was inconvenient to process all the samples in one day. On such occasions the samples were refrigerated and determinations were made as soon as possible.

Measurement of Nitrifying Activity -

Known volumes (5 to 10 ml) of the nitrifying liquor were centrifuged, washed with 0.8% sodium chloride solution and suspended in 100 ml of nitritifying or nitratifying media placed in 250 ml conical flasks. The suspensions of the media containing the test liquors were agitated with the aid of magnetic stirrers. At periodic intervals, samples were drawn from these flasks and examined for their nitrite content and pH value.

The total nitrogen content of the nitrifying liquor sample was determined using aliquots of the same sample. The rate of nitrification was expressed in terms of milligrams of nitrogen oxidized per hour per milligram of TKN.

Reactor Units -

These units were utilized to study the nitrogen losses that occur under controlled environmental conditions. Both pyrex glass aspirator bottles and plexiglass units constructed by laboratory personnel were used. Examples of the plexiglass units are shown in Figure 35.

Different quantities of ODML and poultry manure suspensions in tap water were aerated. The slurries in the reactors were mixed with either magnetic stirrers or paddle type stirrers, fitted through a mercury seal, and driven by electric motors. The air flow to the system was monitored with flow meters. The air bubbling from the system passed through acid traps to collect any ammonia volatilizing from the system.

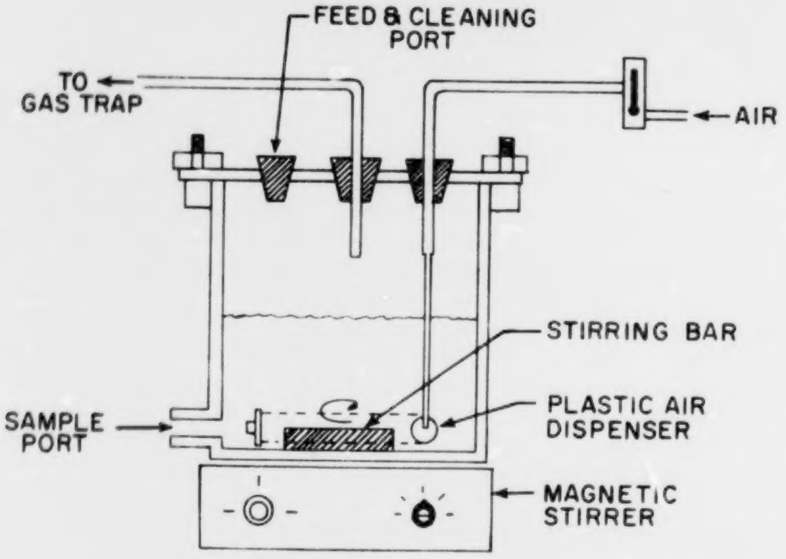
Pilot Plant Oxidation Ditch Studies

The oxidation ditch at the Agricultural Waste Management Laboratory has been operating and evaluated continuously since 1970. The initial evaluation was to stress the oxidation ditch system to its maximum to determine its potential with untreated poultry wastes. This caused the system to be used as an aerated holding tank. Solids concentration ranged up to about 8.5 percent due to high evaporation and non-overflow conditions.

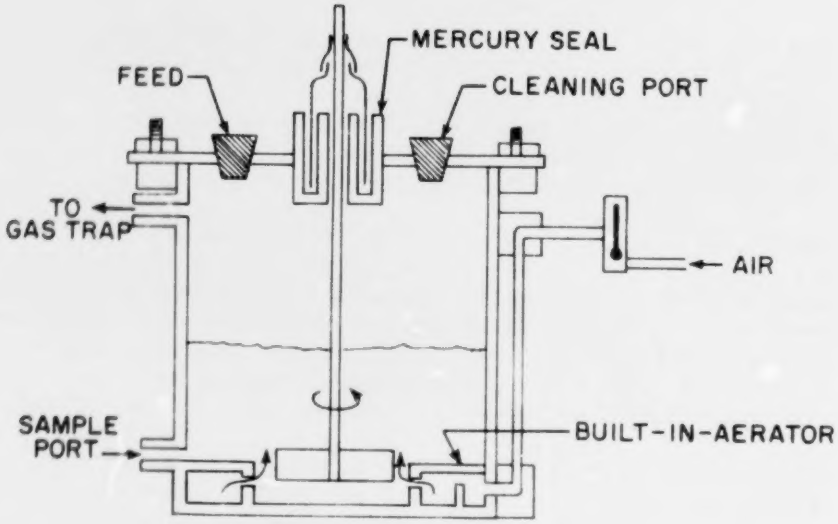
Since it is possible that there may be overflow from oxidation ditches used for poultry operations, during the period of this project it was decided to operate the pilot plant oxidation ditch at various solids levels to evaluate the magnitude and characteristics of the overflow. This permitted nitrogen mass balances to be made. Nitrogen losses in the ditch were related to the varying operating conditions.

The concentration of total solids in the oxidation ditch was varied by altering the water input to the ditch. The operational control of the total solids content necessitated the installation of an automatic overflow in addition to control of water input to the ditch. The data collected in this study included: rotor immersion depth, waste output, water input, rates of oxygen uptake, temperature, COD, total and volatile solids, and organic, ammonia, nitrite and nitrate nitrogen.

Solids concentrations were changed only after a suitable equilibrium period was established. During the study, the immersion depth of the rotor was increased whenever the concentration of dissolved oxygen in the mixed liquor was close to zero. The reduction in dissolved oxygen concentration occurred as a result of the decreased oxygen transfer capabilities of the rotor as the solids concentration increased. Thus an equilibrium period, as defined by the concentration of total solids, consisted of more than one sub-phase if the rotor immersion depth was changed.


FEED & CLEANING PORT
TO GAS TRAP
AIR
STIRRING BAR
PLASTIC AIR DISPENSER
SAMPLE PORT
MAGNETIC STIRRER

REACTOR I


MERCURY SEAL
FEED
CLEANING PORT
TO GAS TRAP
AIR
SAMPLE PORT
BUILT-IN-AERATOR

REACTOR II

Figure 35. Reactors used in laboratory nitrogen control experiments.

In September 1972 the birds were removed from over the oxidation ditch and the operation of the ditch was restarted after 250 new birds were placed in the cages on 17 October 1972. About 300 gallons of ODML that had been saved from the previous operation for purposes of seeding were added to the ditch. Tap water was added to bring up the total volume in the system to 1500 gallons. The rotor was operated at an immersion depth of 1 inch. Several changes were made in the mode of operation throughout the project.

Houghton Farm Oxidation Ditch Studies

In early January 1972, a full scale oxidation ditch waste treatment system was installed in a nearby poultry farm. The system was put in by the owner, Mr. C.L. Houghton, after he had seen the pilot plant oxidation ditch but without detailed design information from the personnel associated with this project. However, since the installation of the system, the project personnel have worked closely with Mr. Houghton to monitor the system and to cause it to operate satisfactorily.

Waste disposal at the Houghton Farm prior to conversion to an oxidation ditch consisted of periodic removal of the stored, liquid manure and disposal on farm land. After spreading, the manure was immediately plowed under. The odors generated by the manure disposal and emitted by the ventilating fans of the production facility caused complaints from neighbors. Based upon the positive results he had seen demonstrated with the Cornell pilot plant oxidation ditch, Mr. Houghton decided to convert his building and install an oxidation ditch.

The Houghton oxidation ditch consists of two separate ditches side by side in the building. The ditches are interconnected to permit liquid equalization. The building is 45 ft by 325 ft. Each oxidation ditch is 15 ft wide, 276 ft long, consisting of two 6 ft raceways separated by a 3 ft barrier. The waste from about 7500 birds is defecated directly into each ditch. Two 5 hp, 27 in. diameter, 6 ft long rotors operate continuously in each ditch. The rotors operate at 111 rpm.

The bird watering system is of a type that permits excess water to fall into the ditches necessitating intermittent removal of the mixed liquor to avoid overflow of the system. The liquid level of the system is allowed to increase between mixed liquor removals. This increase in liquid level results in a variable immersion depth and variable oxygen transfer by the rotor. The rotor immersion depth varies from about 6 in. to 9 in. The liquor is removed by a conventional liquid manure spreader to adjacent fields. The liquor is not odorous and no odor complaints have occurred since the ditches went into operation. The lack of odor has permitted Mr. Houghton to spread the waste closer to his poultry house and residence thus reducing disposal time and costs. Approximately 5000-8000 gallons of the liquor are removed from the ditches each week.

Project personnel had no opportunity to measure the oxygen transfer relationships of the rotor before the wastes were added. The rotors are the same make and diameter as the rotor in the Cornell University pilot plant oxidation ditch permitting extrapolation of data from the pilot plant study to this operation.

Analyses of the oxidation ditch mixed liquor such as COD, TKN, NO_2-N, NO_3-N, total and volatile solids, pH, temperature, oxygen uptake rates, and liquid depth were obtained once or more per week during the first six months of evaluation and one to two times a month thereafter.

Calculation of Nitrogen Losses

A loss of nitrogen has been consistently observed in the aerobic laboratory units containing nitrified poultry wastewater and in the aerobic nitrifying oxidation ditches. This loss has been computed as the difference between the amount of nitrogen that was fed to the system and the nitrogen that was actually present in the mixed liquors plus any nitrogen that was removed deliberately from the system such as for disposal or analysis. These losses were attributed to denitrification and ammonia volatilization. The gas traps in the laboratory systems permitted an estimate of the ammonia volatilization losses. No effort was made to measure ammonia losses in the oxidation ditch studies because of the inherent difficulties in such measurements.

If the possibility of nitrogen loss due to ammonia volatilization is excluded or known, the observed nitrogen losses can be attributed to denitrification. Nitrogen mass balances in the aerobic systems should therefore take into consideration the two sources of nitrogen losses. The relationship between the nitrogen added, nitrogen content of the system and the losses can be expressed by the following:

Total Nitrogen added = Total Nitrogen in the system
+ nitrogen lost due to ammonia volatilization
+ nitrogen lost due to denitrification
+ nitrogen removed from the system for disposal or analysis

RESULTS

General

In laboratory units containing nitrified poultry wastewater and in nitrifying oxidation ditches, losses of nitrogen were observed even though aerobic conditions prevailed in these systems. Losses of nitrogen from a treatment system can occur by two mechanisms; a) volatilization of ammonia, and b) denitrification. Volatilization of ammonia takes place when the pH of a system is in the alkaline range and free ammonia is present. The loss of nitrogen by denitrification takes place under anoxic conditions at the expense of nitrate or nitrite being used as an hydrogen acceptor by the facultative heterotrophs.

When active nitrification is established in a system, the pH generally is below 7. These pH conditions are not conducive for ammonia volatilization. Although volatilization has been observed in laboratory units and the oxidation ditch because of alkaline conditions during the start-up phase, such losses were found to be insignificant once nitrification is established and the pH dropped below 7. Nevertheless a loss in total nitrogen of these systems occurred although the dissolved oxygen concentration was in the range of 1-5 mg/l. Excluding the possibility of nitrogen losses by ammonia volatilization, the loss in total nitrogen is only possible by denitrification.

As a consequence of this observation on nitrogen losses from nitrifying mixed liquors maintained under aerobic conditions, investigations were initiated to study the factors that govern these nitrogen losses. One factor that is considered important is the loading factor, e.g., #COD/#TS or #TKN/#TS. Total solids were used as a parameter because we have found that the determination of suspended solids with concentrated wastes such as the one used in these studies included always a variable proportion of dissolved solids. As the loading is increased, a greater oxygen demand is exerted in the system. In a nitrifying reactor, when a high oxygen demand is exerted because of a high organic loading, there is a good probability of NO_2^- and NO_3^- being used as electron acceptors along with the dissolved oxygen present in the mixed liquor. This is conceivable if it is visualized that the concentration of dissolved oxygen at the surface or interior of a microbial floc may be close to zero. This can be possibly due to a high oxygen uptake exerted by the microorganisms because of the readily available substrate. In such a situation a very low oxygen tension or even anaerobiosis can occur at the surface of the floc and the NO_2^- and NO_3^- present within its sphere of influence may be used as electron acceptors and thus denitrified even though a certain concentration of dissolved oxygen is present in the bulk of the mixed liquor.

Experimental

To obtain information on factors affecting nitrogen losses under aerobic conditions, three batch reactors were used to study the effect of solids concentration on such losses of nitrogen in a nitrifying mixed liquor. With an increase in the biological solids concentration, the oxygen demand of the mixed liquor will increase and the oxygen transfer capability of an aerator may decrease. In these experiments the total solids concentration was used as a measure of the microbial floc as well as the inert solids contained in the mixed liquor.

Reactor I -

Three liters of an actively nitrifying oxidation ditch mixed liquor were placed in a 4 liter aspirator bottle and air was supplied at 8 SCFH. The total solids concentration in the reactor was 36,800 mg/l.

Reactors II and III -

The conditions were the same as in Reactor I, except that the reactors contained different solids concentrations, i.e., 18,500 and 9450 mg/l respectively.

TKN, NO_2-N, NO_3-N, NH_4-N, COD, total solids, dissolved oxygen, and

oxygen uptake rates were measured routinely. Typical data are shown in Figure 36. Nitrogen balances were computed and the results are presented in Table 15.

The results indicated that Reactor I, which contained more solids and exerted a higher initial oxygen uptake rate than the other two reactors, had a total nitrogen loss of 13%. There was no nitrogen loss in Reactors II and III. The dissolved oxygen concentration in the mixed liquor of Reactor I was initially 2.6 mg/l and increased to about 6.5 mg/l towards the end of the experimental run. During the same period the oxygen uptake rate decreased from a maximum of 48 mg/l/hr to 6.5 mg/l/hr indicating that the waste was stabilized. The high initial oxygen uptake rate created by the mixed liquor of Reactor I was presumably due to the high concentration of readily available substrate. In Reactors II and III the oxygen uptake rate of the mixed liquor was considerably less than that of the mixed liquor of Reactor I and no nitrogen losses were observed. The dissolved oxygen levels were higher in these reactors. The nitrogen loss in Reactor I could have been due to the denitrification in the vicinity of the microbial flocs as a result of the creation of localized anaerobiosis which in turn was a consequence of the high oxygen demand exerted in the system. In Reactors II and III, such localized anaerobic conditions might have been as large because of lower oxygen demand.

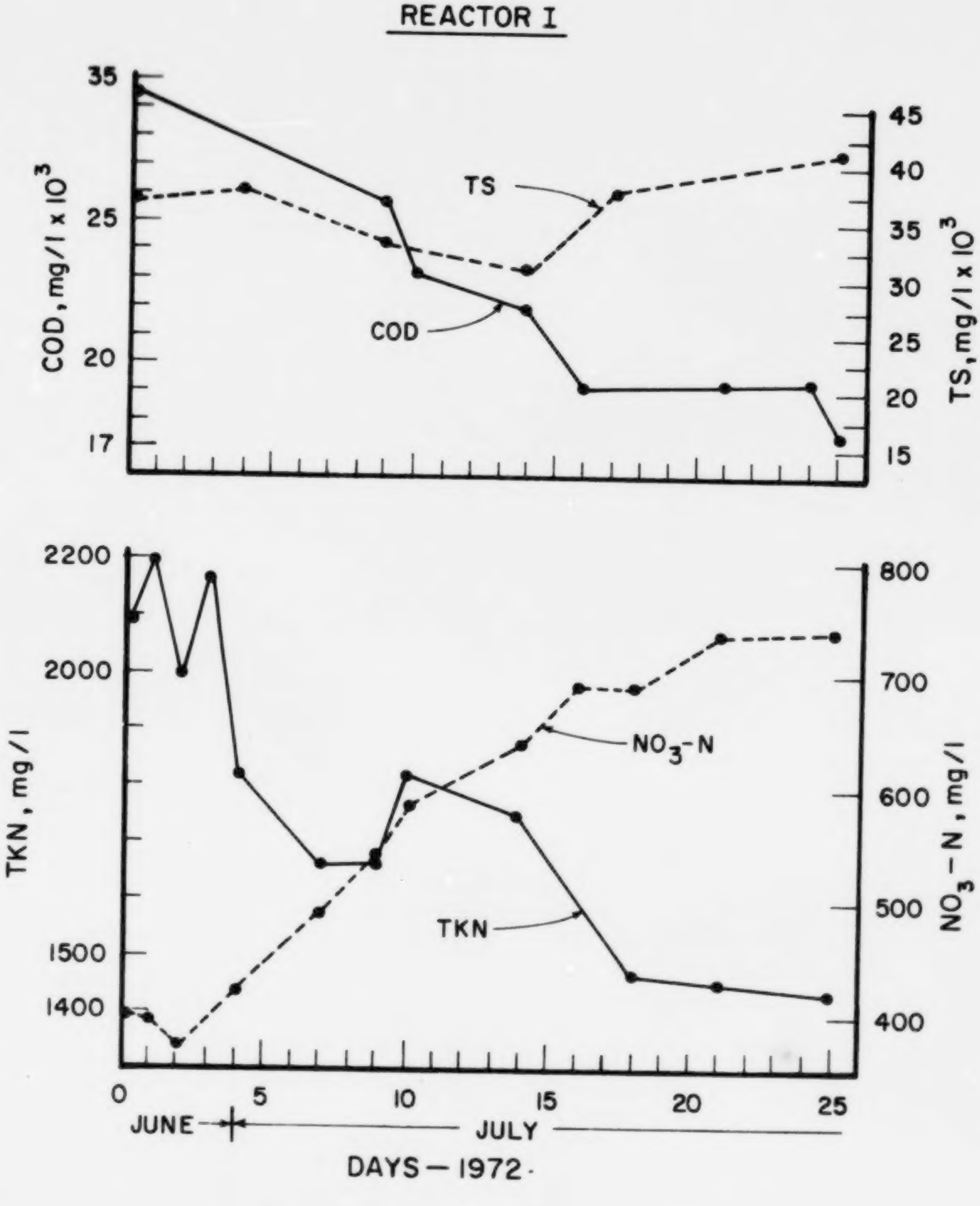


Figure 36. Change of characteristics during batch treatment of poultry wastes.

Table 15. NITROGEN BALANCES IN BATCH NITRIFYING UNITS AT DIFFERENT INITIAL SOLIDS CONCENTRATION - LABORATORY STUDY

Reactor	Period of operation - (days)	Initial total solids concentration (mg/l)	Dissolved oxygen (mg/l)		O_2 uptake rate (mg/l/hr)		Total nitrogen (mg/l)		Nitrogen Loss (%)
			Init.	Fin.	Init.	Fin.	Init.	Fin.	
I	25	36,800	2.6	6.5	48	6.5	2487	2156	13.3
II	14	18,500	6.0	6.5	24	9.5	1258	1261	0
III	14	9,250	6.5	6.3	12	4	622	615	0

To confirm the results obtained with Reactor I, two more reactors were used. These reactors contained total solids concentrations of 3.96 and 4.95% respectively. In these two reactors, 18 and 19% of the total nitrogen was lost in 10 and 6 days, respectively. During this time period the dissolved oxygen concentrations were greater than 2 mg/l.

From these experiments it was seen that while the aeration rate was constant, nitrogen losses from a nitrifying reactor can be increased by increasing the solids concentration and thereby the oxygen demand.

Another series of experiments were used to further investigate these relationships. Instead of using a nitrified mixed liquor as in the above studies, two batch reactors were set up using raw poultry wastewater to increase both solids concentration and oxygen demand.

Reactor Ia

Two liters of an actively nitrifying mixed liquor were placed in a 4 liter unit. One liter of a poultry manure suspension containing 100 g of wet manure/liter was added to this reactor.

Reactor Ib

Two liters of the same nitrifying seed used for Reactor Ia were added to another unit. One hundred ml of the same poultry manure suspension was added daily for 22 days. When the liquid level in the unit reached 3 liters, the unit was operated on a fill and draw basis with 100 ml of the poultry manure suspension being added each day after 100 ml of the mixed liquor was withdrawn. This procedure was followed to distribute the oxygen demanding material over a period of time rather than in one dose as was done in Reactor Ia.

Reactor Ic

In a third reactor, three liters of the nitrifying mixed liquor that was used as the seed for the above reactors were kept and used as a control. No waste was added to this unit.

Humidified air was bubbled through all the reactors at a rate of 8 SCFH. TKN, NO_2-N, NO_3-N, NH_4-N, total solids, dissolved oxygen and the oxygen uptake rate of the mixed liquors were measured routinely. Ammonia losses from these reactors were measured by trapping the volatilized ammonia in a standard acid solution. Nitrogen balances were obtained and the percent nitrogen losses due to ammonia volatilization and denitrification were computed. The results from this study are presented in Table 16.

Table 16. NITROGEN LOSSES DUE TO AMMONIA VOLATILIZATION AND DENITRIFICATION - BATCH STUDY

	REACTOR		
	Ia	Ib	Ic
Period of operation (days)	15	22	15
Total solids, mg/l			
Initial	21,400	9,560	7,580
Final	14,000	23,680	7,600
D.O., mg/l			
Initial	0.3	3.5	5.0
Final	6.5	3.5	7.0
O_2 uptake rate, mg/l/hr			
Initial	80	36	22
Final	4	265	2
Total nitrogen, mg/l			
Added	1,465	2,200	420
Accounted	765	1,820	405
% N losses			
Ammonia volatilization	31	5	4
Denitrification	17	12.5	0

The nitrogen losses were the highest in Reactor Ia. Of the 48% of the total nitrogen lost, 31% was accounted for by losses due to ammonia volatilization. The remaining 17% was lost due to denitrification. Thus if treatment systems are started with a heavy load of TKN, significant losses of nitrogen can be expected due to ammonia volatilization. The nitrate that was added in the nitrifying seed was lost from the mixed liquor of Reactor Ia during the first day of its operation. This indicates that the high oxygen demand of the mixed liquor and the low initial dissolved oxygen concentration (0.3 mg/l), might have created anaerobic conditions at the floccular level resulting in denitrification. Such losses of NO_3^- were not noticed either in Reactor Ib or Ic during the first day of operation. In these reactors the oxygen uptake rates were significantly lower, and the dissolved oxygen concentrations were significantly higher than the Reactor Ia during their entire operation.

Denitrification losses can be expected to be lower in systems treating nitrogenous wastes when they are loaded uniformly. For example, when Reactor Ib was fed with poultry wastewater to reach a theoretical total nitrogen concentration of 1425 mg/l on the eighth day, 1395 mg/l of TN were accounted for. Only 10 mg N/l was lost due to ammonia volatilization. The 20 mg N/l that was not accounted for could be due to denitrification or experimental error.

In Reactor Ib, until the eighth day the dissolved oxygen in the mixed liquor was approximately three mg/l but during the period of 8-13 days, nitrogen losses occurred in the system. The dissolved oxygen concentration in the mixed liquor during this period was about 1.0 mg/l. This may have been due to faulty aeration. A total nitrogen loss of about 15% was observed during this period, although nitrification continued to occur simultaneously as noticed by an increase in the NO_3-N concentration. After this period no significant loss of nitrogen was noticed and the dissolved oxygen in the mixed liquor was above 3.0 mg/l.

The loss of nitrogen in Reactor Ia was significantly higher than in Reactor Ib, although the initial total nitrogen in Reactor Ia was in the same range of the total nitrogen found on the eighth day in Reactor Ib. The difference in nitrogen losses between these two reactors lies in the manner in which these reactors were operated with respect to loading rates as well as the concentration of dissolved oxygen that was able to be maintained.

The nitrogen loss in Reactor Ic was very small and was due to the high concentration of dissolved oxygen prevailing throughout its operation and the relatively low oxygen uptake rate of the mixed liquor.

By starting a system with a single high loading initially (Ia) rather than distributing the same by daily installments (Ib), it was possible to obtain a considerable solids reduction. In Reactor Ia the initial total solids concentration of 21,440 mg/l decreased to 11,250 mg/l amounting to about 50% reduction in 22 days. The solids concentration in Reactor Ib, however, increased from 9560 mg/l to 23,680 mg/l during the same period. An increase in the solids concentration was expected because the manure suspension was added daily to this reactor without removing any mixed liquor up to the fourteenth day. The solids level on the fourteenth day in the reactor was 20,000 mg/l which is only slightly lower than the concentration of solids on the twenty-second day. Although a good total solids balance could not be made in this investigation, it can be said that if any solids reduction had occurred in Reactor Ib, on a percentage basis it was much less than the 50% of solids reduction observed in Reactor Ia. The high solids reduction in Reactor Ia presumably was due to volatilization of ammonia, denitrification, oxidation of organic matter, lysis of cells and further oxidation of the cell constituents under prolonged aeration. The absence of significant loss of solids in Reactor Ib possibly was due to minimal losses of nitrogen and less lysis and subsequent oxidation of biological solids.

From the above studies it appears that by maintaining a certain minimum dissolved oxygen concentration in the mixed liquor and by manipulating the loading rate, it may be possible to increase the total nitrogen losses by denitrification while maintaining an actively nitrifying system.

The nitrogen loss in aerobic systems is related to the relationship between oxygen demand and oxygen input. Altering the solids concentration will affect the oxygen input by affecting the oxygen transfer capability of the aeration system. Altering the aeration rate while maintaining a constant loading to the reactor is another way to vary the oxygen input. To investigate the effect of aeration rate and hence oxygen input or aerobic nitrogen losses, three additional batch studies were conducted.

One liter of a well nitrified mixed liquor was added to 250 ml of a poultry manure suspension. Aeration was held at 10 SCFH. One hundred-fifty ml of the poultry manure suspension was added daily until the volume of mixed liquor in the reactor reached 2.5 liters. Thereafter a daily fill and draw procedure was maintained in which 250 ml of the manure suspension was added after 250 ml of the mixed liquor was withdrawn. The reactors were tightly sealed and stirred magnetically. The air outlet of the reactors was connected to a train consisting of a foam trap, two traps containing 0.2 N sulfuric acid, and a final trap containing boric acid. The traps were to collect any volatilized ammonia.

Some ammonia was volatilized in the beginning of the experiments. However, once nitrification occurred, no ammonia was volatilized. Nitrogen balances were made in the three reactors after equilibrium was established to obtain baseline data (Table 17). Variations in losses of ±10% are not significant due to the sampling and analytical errors inherent in the balances. Thus the fact that an apparent nitrogen gain occurred may have been due to analytical errors. The apparent gain also indicated that no nitrogen losses occurred under the baseline conditions.

After baseline equilibrium conditions were established, the air flow rates in two of the reactors were altered to 6 and 2 SCFH. All other operational factors remained the same. Problems did occur in the operation of the BIII reactor. Occasionally the magnetic stirrer stopped, ammonia losses increased and nitrification slowed. A close watch was kept on the unit to minimize such problems. Sufficient equilibrium data was obtained under the altered aeration conditions to compare the nitrogen losses in the reactors (Table 18).

The results (Table 18) indicate that as the aeration rate per unit volume, and hence the oxygen input, decreased the nitrogen losses due to denitrification increased. Even with the operational problems in Reactor BIII, adequate nitrification took place to obtain the noted denitrification losses.

The operation of the reactors at the low aeration rates was difficult. Slight decreases in the air flow or mixing rates resulted in cessation of nitrification. The pH of the mixed liquor increased and the conversion of organic nitrogen to ammonia nitrogen increased. Some ammonia volatilized under these conditions. When these conditions were corrected, production of nitrites and nitrates again occurred confirming the ability of the nitrifying organisms to continue to exist under inhibitory conditions and to respond when the inhibitory conditions were alleviated.

Further work is continuing to more precisely determine the relationships between oxygen input, oxygen demand, and nitrogen losses. These studies are being done under controlled laboratory conditions.

Oxidation Ditch Studies

General -

Samples of the wastes excreted by the birds at the pilot plant and the Houghton Poultry Farm were obtained periodically over the project period. The samples were analyzed for a number of parameters that were used in calculating mass balances. The samples were collected by randomly putting a collection pan under one cage of birds for 24 hours. The

Table 17. NITROGEN BALANCE ON BATCH REACTORS AT CONSTANT AERATION RATE

Reactor	Aeration rate (SCFH)	Nitrogen loss[a] (%)
BI	10	+15
BII	10	+12
BIII	10	+ 4

[a] The losses were computed over a ten day equilibrium period. The + sign indicates no losses occurred and an apparent increase was noted.

Table 18. NITROGEN BALANCE ON BATCH REACTORS AT DIFFERENT AERATION RATES

Reactor	Aeration rate (SCFH)	Nitrogen loss[a] (%)
BI	10	-13
BII	6	-17
BIII	2	-52

[a] The minus sign indicates that nitrogen was unaccounted for. The losses were assumed to be due to denitrification because all other loss possibilities were accounted for.

samples were diluted with tap water, blended, and analyzed. The average results of these analyses are presented in Table 19.

The excreta of the birds at the pilot plant were collected and analyzed over two separate periods. The periods reflect the two different groups of birds that were in the cages. With few exceptions, the characteristics of the excreta during the two periods are comparable. The birds at the Houghton Farm were fed different rations. This and the sampling problems noted in Table 19 account for the differences in characteristics between the birds at the two locations.

Pilot Plant -

i) General operation - The operation of the pilot plant oxidation ditch was varied throughout the project period to investigate a number of operational parameters and to investigate nitrogen losses under controlled conditions. The operational procedures and some analyses of the mixed liquor during the project periods are shown in Figures 37 and 38. The concentration of dissolved oxygen in the mixed liquor fluctuated depending upon the solids concentration and rotor immersion depth. Dissolved oxygen levels were always above zero and at times were up to 6 mg/l. The ODML contained organisms associated with satisfactory aerobic treatment, i.e., flagellated, free swimming and stalked protozoa, rotifers, and bacteria.

The pilot plant oxidation ditch was primarily a nitrate production unit. Even with nitrification to the nitrate form, the pH remained near neutral. The performance of the system appeared affected by seasonal temperature variations. Even though the birds and the ditch were housed in a heated, enclosed building, the ditch was constructed in the ground and is affected by the ground temperature. Mixed liquor temperatures decrease in the fall and increase in the spring. The lowest temperature in the ditch was about 12°C in January and increased gradually to over 20°C in June.

ii) Nitrogen loss - In September 1972, the chickens were taken out from the pilot plant facility and there was an opportunity to study the denitrification of the oxidation ditch mixed liquor _in situ_. The objective of this investigation was two-fold: a) to study the time required for removing the NO_3^- by denitrification and the subsequent opportunity for renitrifying the denitrified mixed liquor, and b) to study the activity of nitrifying organisms under denitrifying conditions.

On September 7, 1972, the rotor in the oxidation ditch was stopped and denitrification of the mixed liquor started without the input of poultry wastes. On September 21, 1972 the rotor was started and run for 30

Table 19. CHARACTERISTICS OF THE POULTRY EXCRETA ENTERING THE OXIDATION DITCH SYSTEMS

	Pilot Plant		Houghton Farm
	6 June 1972 to 24 August 1972	15 November 1972 to 17 May 1973	3 May 1972 to 3 April 1973
Grams per bird per day			
Total weight of excreta	112	123	210[a]
Dry weight of solids excreted	30	31	38
Volatile solids excreted	22	22	29
Percent on a dry weight basis			
Total solids content in excreta	27	25	18
Total volatile solids/total solids	71	72	76
Milligrams per gram of total solids			
COD	729	658	797
BOD_5	200	140	214
TKN	88	79	83
NH_4^+-N	6	4	6

[a] Feeding and watering devices at the farm are of a different design and had an influence on the samples collected. Spilled water and some feed were in the samples collected at the Houghton Farm.

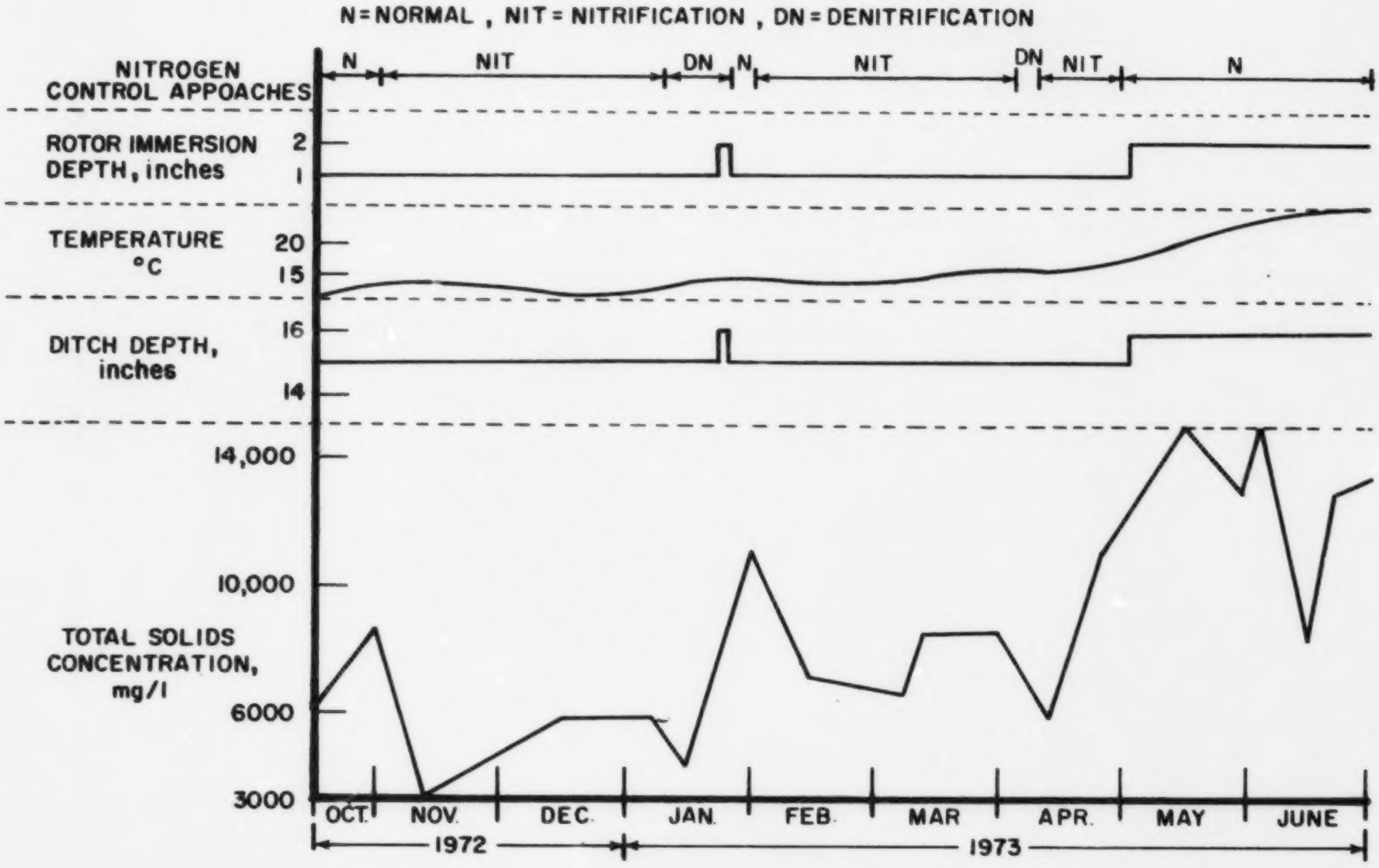


Figure 37. Operational modes, solids and temperature data for the pilot plant oxidation ditch.

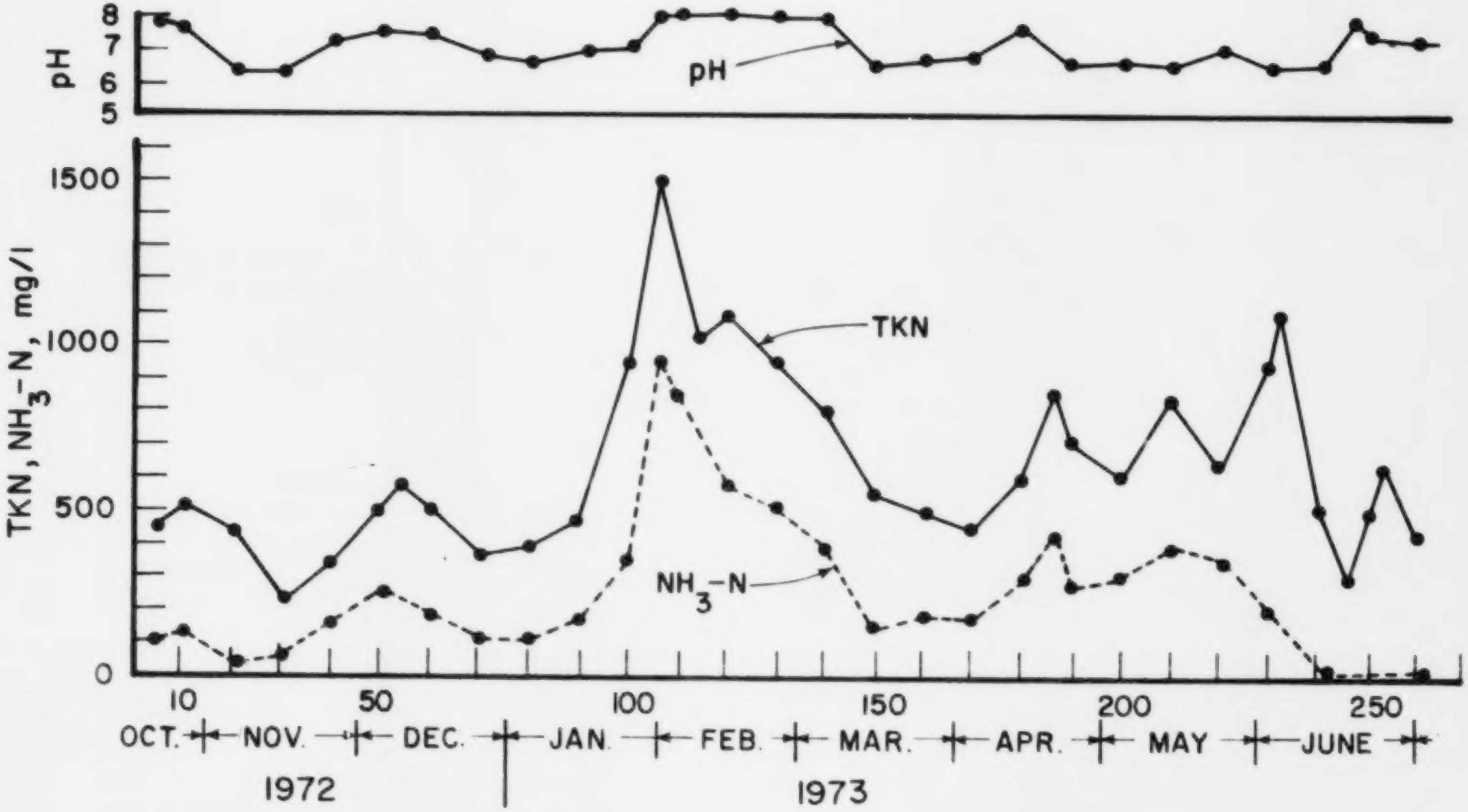


Figure 38. TKN, ammonia nitrogen and pH in the pilot plant oxidation ditch.

minutes to mix the ditch contents to ensure a good contact between the microorganisms and the substrate. The denitrification in the ditch was stopped on October 4, 1972. Five hundred gallons of the mixed liquor was pumped into a separate tank and aeration resumed to renitrify the denitrified mixed liquor. The TKN and NO_3-N concentration was measured routinely. The results are presented in Figure 39. Most of the NO_3-N was lost in the first 15 days. About 90% of the initial NO_3-N was lost over the entire 27 day denitrification period. The unexpected decrease in TKN of the mixed liquor may be due to sampling error, because during the denitrification phase, settling and compaction of the MLSS occurred.

Renitrification of the mixed liquor was possible even after it was subjected to 27 days of denitrification confirming the observations made in previous studies.

During the denitrification of this study, the nitrifying activity, i.e., activity of nitrosomonas organisms in the mixed liquor, decreased (Table 20). Although the activity of the nitrite forming organisms decreased rapidly, active organisms persisted even after two months. Denitrification conditions prevailed for 27 days of this period. The mixed liquor could be renitrified successfully after it was denitrified and when the nitrifying activity was only about one tenth that which existed at the beginning of the denitrification period.

Table 20. ACTIVITY OF NITROSOMONAS IN A DENITRIFYING MIXED LIQUOR

Day	Nitrosomonas activity mg NO_2-N/l/hr/mg TKN/l
0	53.3×10^{-4}
4	48.1×10^{-4}
6	26.0×10^{-4}
13	9.0×10^{-4}
29	4.6×10^{-4}
54	3.9×10^{-4}
62	4.7×10^{-4}

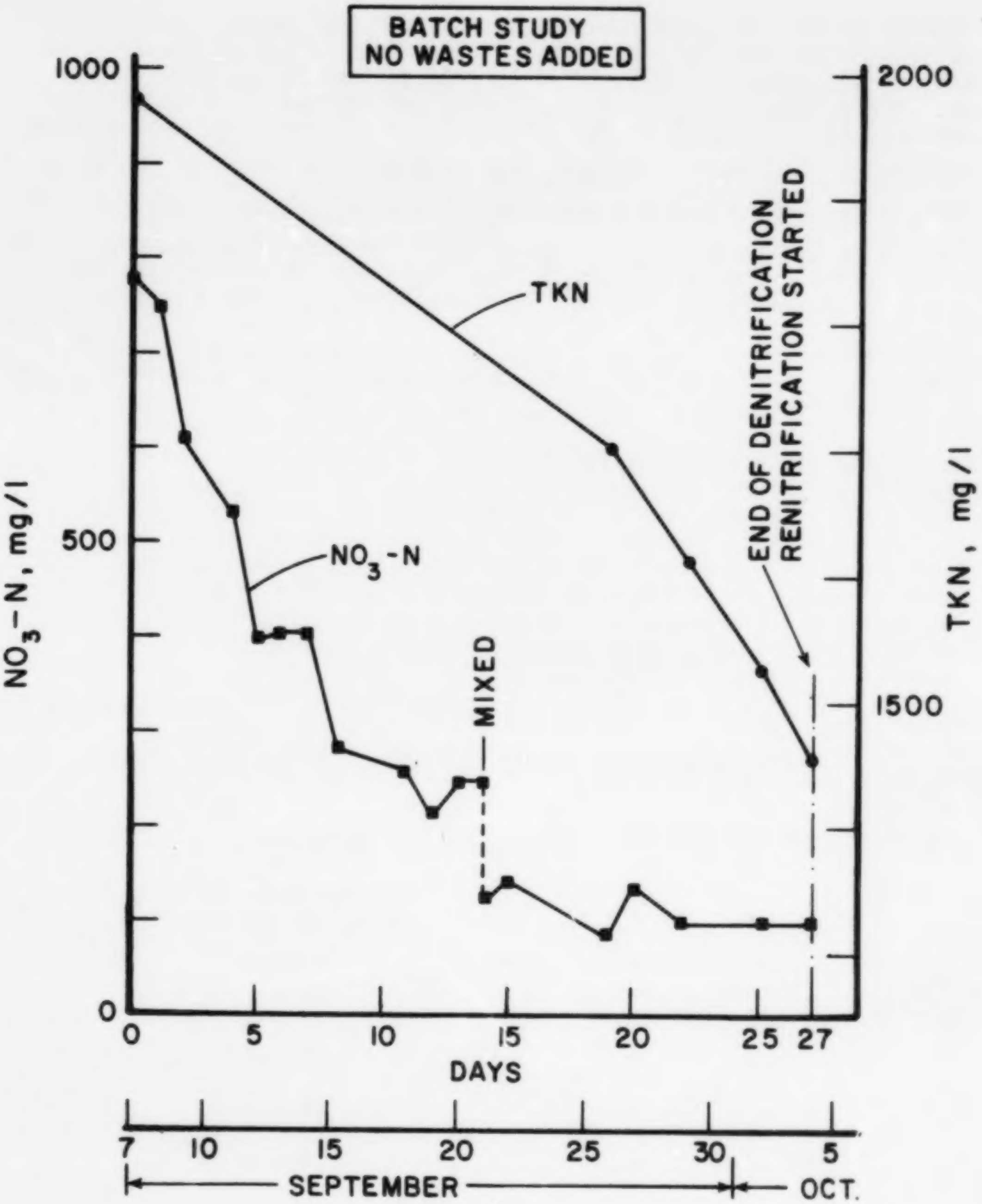


Figure 39. *In situ* denitrification of pilot plant oxidation ditch mixed liquor.

The results of this study confirm that the denitrification of the nitrified poultry waste proceeds slowly in the absence of an exogenous oxygen demand and that renitrification of the denitrified mixed liquor is possible even after it is subjected to a prolonged denitrification of as long as a month.

After this initial in situ denitrification study, the ditch was placed into operation as a flow through unit as described earlier. Two additional in situ denitrification studies were made in the ditch, one in January 1973 and the other in April 1973. In these latter studies, the birds continued to add wastes to the ditch thus adding an additional oxygen demand for denitrification. In both studies, the rotor was turned on briefly each day to mix the ditch contents. In the January study no overflow was permitted and in the April study overflow did occur. Results obtained in these denitrification studies are presented in Figure 40.

The detailed analytical results relating to nitrogen in the pilot plant oxidation ditch treatment system are given in Appendix A-II. The nitrogen input to the oxidation ditch was computed by multiplying the number of birds in the cages above the ditch by the average nitrogen content excreted daily by a bird.

When the oxidation ditch was filling, effluent was not wasted. Hence the output of nitrogen was zero. For other phases of operation, the difference between the nitrogen input and output of the ditch was used in determining the net output. The total nitrogen in the ditch determined by the actual analysis was known. The difference in the nitrogen content in the ditch between two consecutive periods was given as the change in the nitrogen content of the ditch. The difference between the actual amount of nitrogen retained in the ditch in a given period and the change in nitrogen content as measured by actual analysis of the mixed liquor was noted as the loss. The average loss or gain in nitrogen content of the system per day during each of the periods was obtained. From the data presented in Appendix A-II, the percentage losses of nitrogen were computed and are given in Figure 41. The loss of nitrogen (about 73% observed during the initial filling period is high and may be due to: a) ammonia volatilization which was greater when the system was restarted; b) some incidental denitrification of NO_2 and NO_3 contained in the seed, c) errors in obtaining a representative sample of the mixed liquor, and d) errors in estimating the TN input to the ditch. Compaction of the solids in the mixed liquor took place whenever the rotor was stopped, and it was very difficult to obtain a uniform sample. TKN estimates of the mixed liquor samples generally tended toward low figures.

In the first flow through period (November 1, 1972 to January 9, 1973), the loss in nitrogen was about 31%. This was primarily due to denitrification even though "aerobic" conditions prevailed in the system.

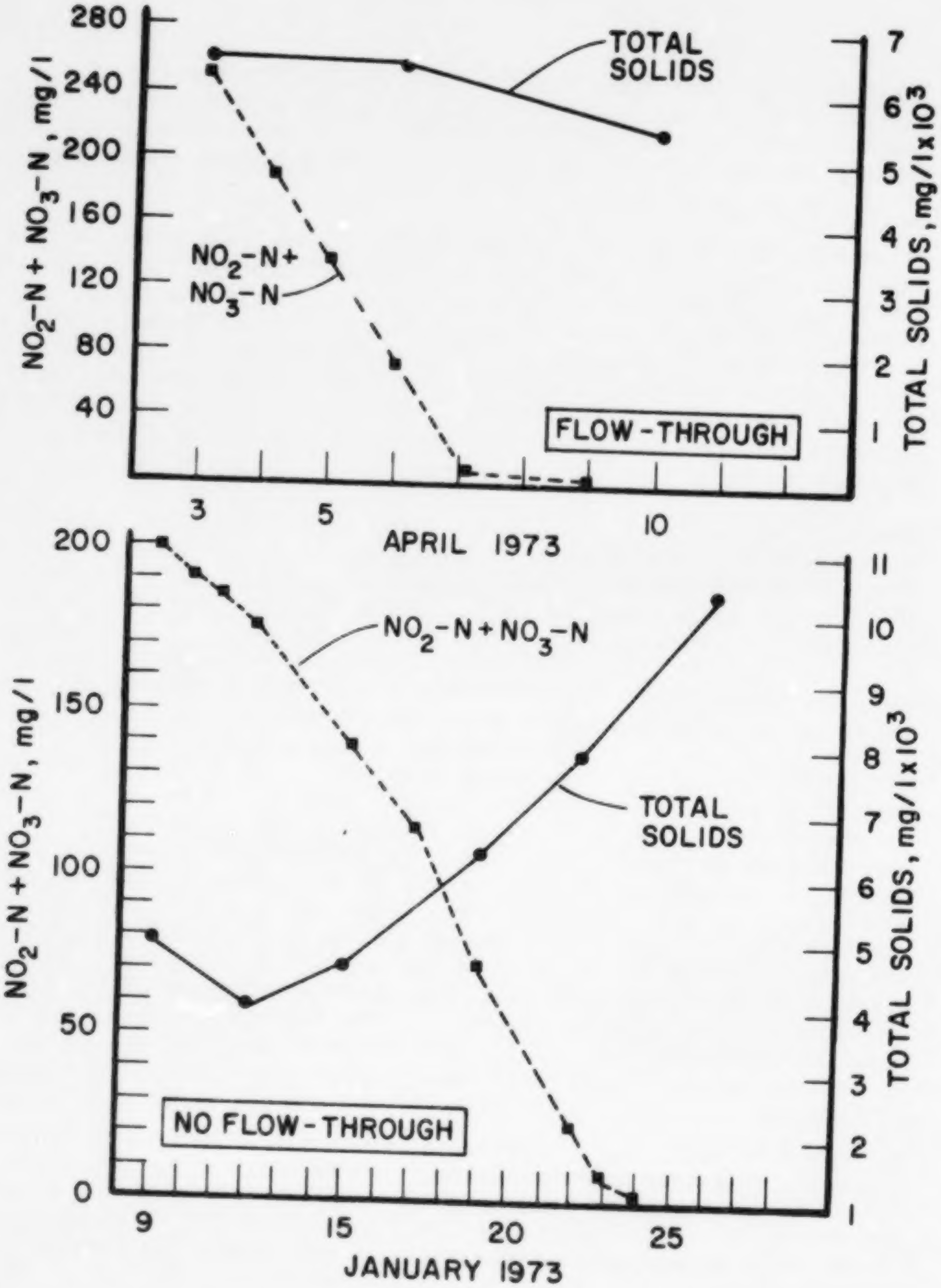


Figure 40. _In situ_ denitrification of pilot plant oxidation ditch mixed liquor with wastes added.

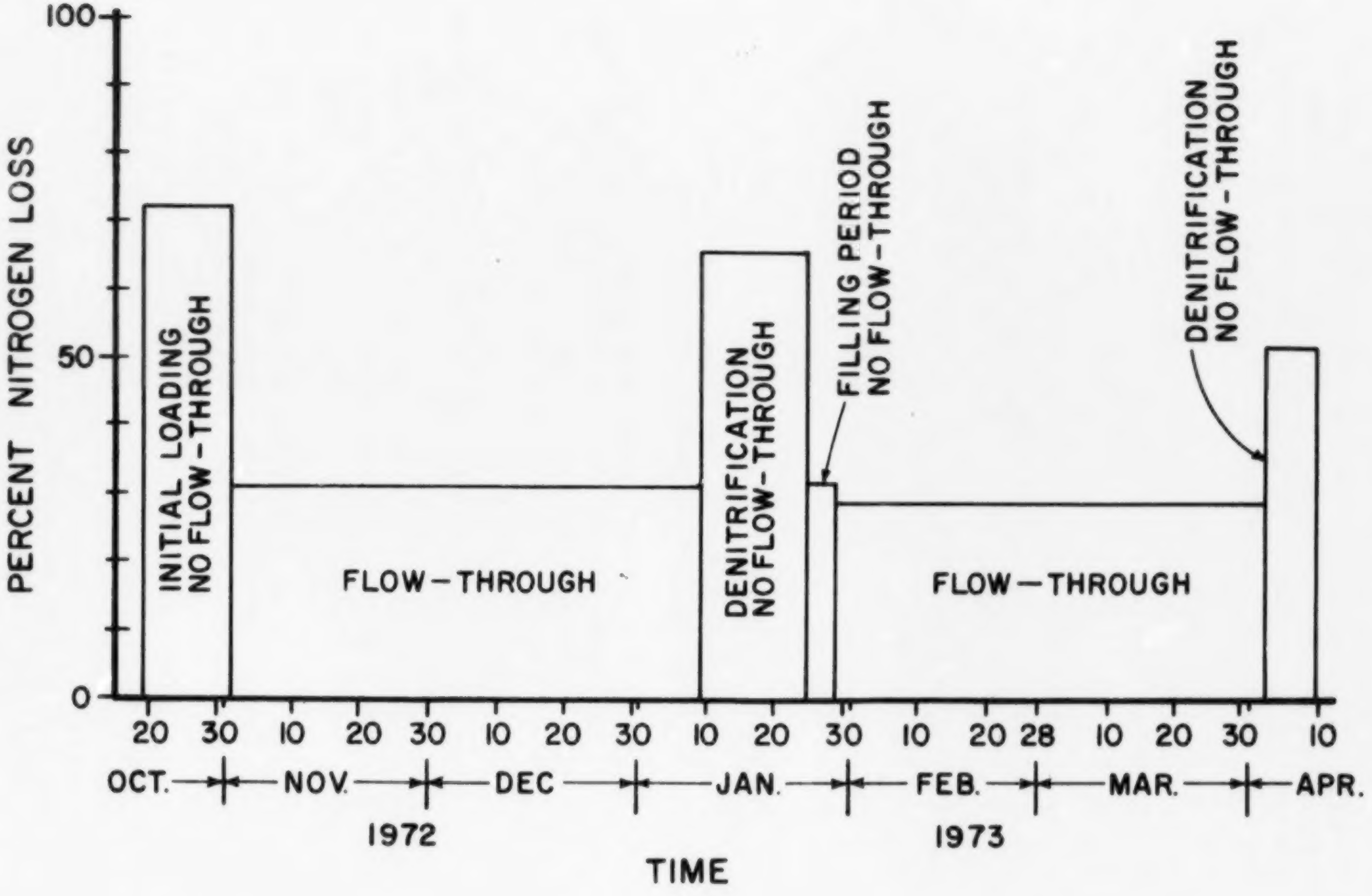


Figure 41. Percent nitrogen losses during the operational modes of the pilot plant oxidation ditch.

Ammonia volatilization was negligible. The pH of the ODML was well below 7.0 and there was active nitrification. Therefore, the losses of nitrogen observed in the system could be attributed to denitrification even though there was active nitrification in the system.

In the denitrification phase from January 9 to 25, 1973, the nitrogen loss was about 66%. During this denitrification period, mixing was provided by operating the rotor for about one-half hour every day. It is doubtful whether any significant part of the nitrogen input into the ditch during this period was nitrified. The losses of nitrogen input as indicated in this period only represent the loss of the nitrites and nitrates which were in the mixed liquor at the start of the denitrification period.

The nitrogen losses in the second filling period were not as high as during the first period since the ditch contents were well equilibrated and nitrification was induced rapidly due to the presence of adequate numbers of nitrifying organisms in the seed material. The nitrogen loss during this period was 32%.

The second flow through period also showed a nitrogen loss (about 29%) comparable to the first flow through period (about 31%). These losses were primarily due to denitrification as the pH value of the ODML was low and unfavorable for ammonia volatilization.

The nitrogen losses during the second denitrification period was 52%, less than that encountered during the first denitrification period. This may be due to the lower amount of oxidized nitrogen present in the ditch during this period as compared to that of the first denitrification period. Some oxidized nitrogen was lost via the effluent as the ditch was operated on a continuous flow basis during this period. The rotor was turned on for about eight hours per day during this period to provide mixing. With such an operation, the denitrification rates were higher as compared to the rates obtained during the previous denitrification period when mixing of the contents of the ditch was provided by operating the rotor for one-half hour daily.

Because of the difference in time periods for the denitrification periods and the regular flow through periods of the ditch, losses due to denitrification during continuous operation of the ditch were much higher than the losses achieved during deliberate denitrification. The total loss of nitrogen due to the deliberate denitrification in the two denitrification stages was about 8% as compared to 23% loss attributable to denitrification under "aerobic" conditions, i.e., continuous operation of the rotor in the ditch. The amount of nitrogen lost during the two filling periods was 7.3% of the total nitrogen input to the oxidation ditch during the overall period. This loss was perhaps due to ammonia volatilization occurring in the system when the pH value of ODML was high. High pH values and high NH_4^+ concentrations were observed during the filling periods.

The NO_2-N and NO_3-N and the total solids contents of the ODML at different times during the two denitrification periods were noted in Figure 40. The rates of denitrification were 0.08 and 0.24 mg of oxidized nitrogen per hour per gram of total solids, respectively, during the January and April denitrification periods. Adequate mixing appears to be essential for achieving better denitrification rates. The mixing did not inhibit denitrification.

An overall summary of the nitrogen balance in the oxidation ditch is shown in Figure 42. A summary of the nitrogen losses over the period of the oxidation ditch operation, October 1972 through April 1973, is indicated in Table 21.

Table 21. NITROGEN LOSS IN OXIDATION DITCH SYSTEM*

	%
Total N loss during flow-through stages	23.2
Total N loss during denitrification	8.0
Total N in effluent	62.1
Total N loss during the two filling periods	7.3
Total	100.9

*Expressed in terms of the initial estimated nitrogen input to the system

During the first "flow-through" stages of the oxidation ditch, nitrification occurred. At the same time significant amounts of nitrogen were lost. This was presumably due to localized denitrification in the anoxic zones of the floc since ammonia volatilization was negligible. The probability for nitrogen loss through this mechanism may be high in a nitrifying system if the localized anoxic conditions for denitrification are increased while maintaining active nitrification. This may be achieved by increasing the solids concentration. Addition of

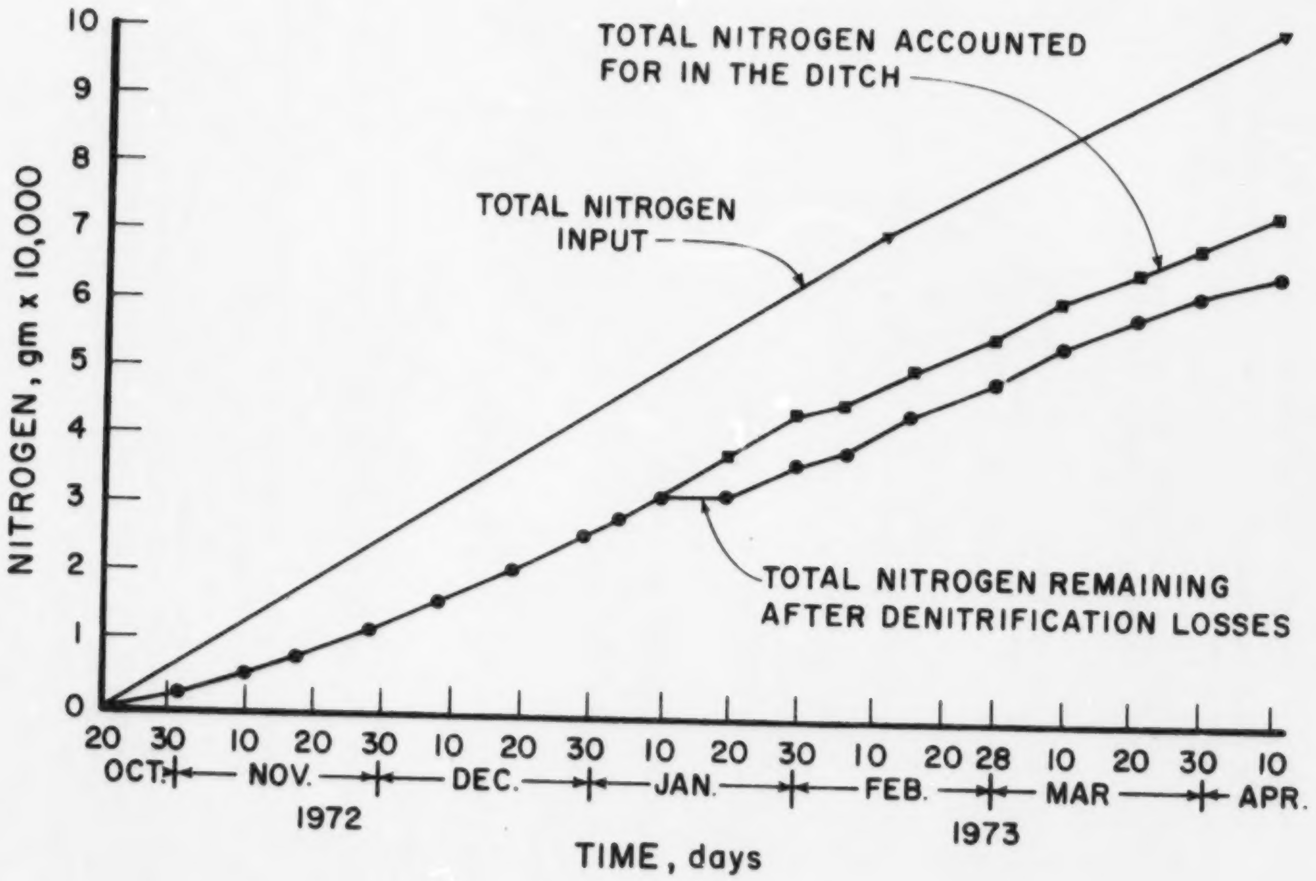


Figure 42. Nitrogen changes in the pilot plant oxidation ditch.

raw manure will increase both the suspended solids content and the oxygen demand of the system and increase the probability for anoxic conditions in the microbial floc. Under these circumstances, the probability for denitrification of NO_2 and NO_3 will increase.

An attempt was made to compare the oxygen uptake rates of the ODML (expressed as mg O_2/hr per gm solids) during each flow through period and the corresponding percent nitrogen losses. The available data was meager and the results were inconclusive. More controlled studies could determine the actual relationship between oxygen demand and nitrogen losses in an aerobic system.

iii) Recent Operation - In a continuing phase of these studies at the pilot plant, attempts are being made to control the solids content of the oxidation ditch mixed liquor without adding fresh water. The mixed liquor is being pumped intermittently into a settling tank and the supernatant liquid is returned to the ditch (Figure 43). The mixed liquor is pumped into the settling tank at intervals of eight hours. The actual duration of pump operation is 4.5 minutes at each interval.

In addition to monitoring the total solids content, chemical analysis of the mixed liquor from the ditch and the supernatant liquor from the settling tank is being made on a regular basis. The results of the nitrogen data collected over the period of June 28, 1973 to July 10, 1973 are given in Table 22 which indicate that denitrification has been occurring in the settling tank. These studies will be continued to develop procedures for nitrogen control in an oxidation ditch-liquid recycle system.

Table 22. NITROGEN CONTENTS OF ODML AND SUPERNATANT FROM SETTLING TANK

	Date of Sampling							
	6/29		7/3		7/6		7/10	
	ODML	ST*	ODML	ST	ODML	ST	ODML	ST
NH_4^+-N, mg/l	0	13	5	18	8	18	0	22
NO_2^--N "	0.8	2	3	0.9	0.8	13	1	41
NO_3^--N "	250	175	245	175	235	75	230	3
TKN "	431	74	395	92	487	80	511	146

*Supernatant from settling tank

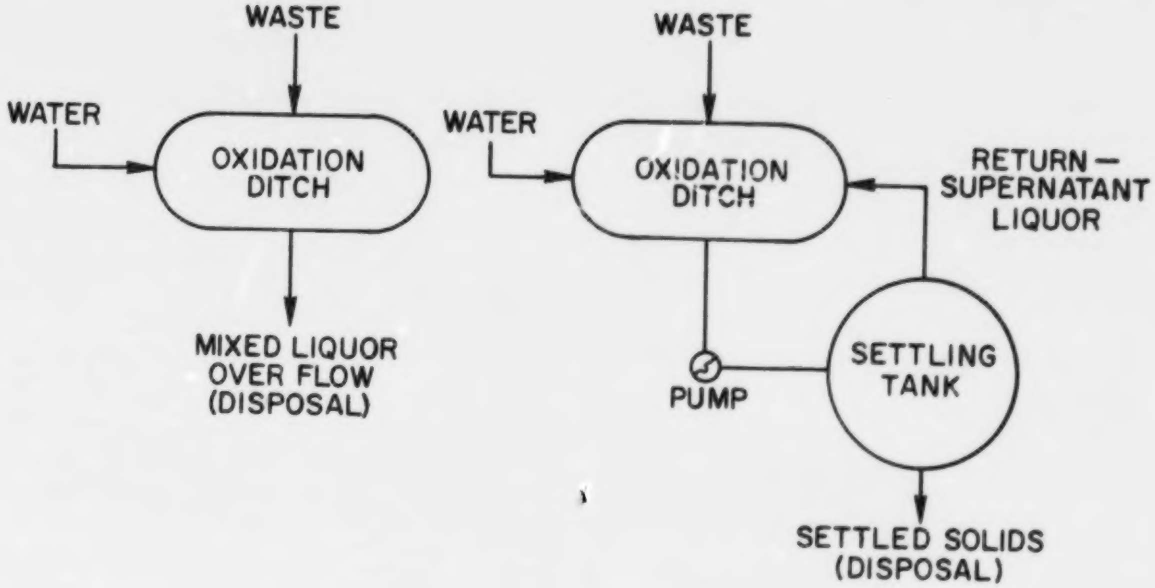

WASTE
WATER
OXIDATION DITCH
MIXED LIQUOR OVER FLOW (DISPOSAL)
WASTE
WATER
OXIDATION DITCH
RETURN — SUPERNATANT LIQUOR
PUMP
SETTLING TANK
SETTLED SOLIDS (DISPOSAL)

Figure 43. Mode of operation of oxidation ditch for for maintaining constant solids level.

Houghton Poultry Farm -

i) General Operation - There have been two phases of operation since the oxidation ditches were installed at the Houghton Poultry Farm in January 1972. Phase I existed for the first 78 days of data collection. The liquid depth was maintained at six to eight inches and the rotor immersion depth varied from four to six inches. Thus the utilized ditch capacity was 0.88 to 1.2 ft^3 per bird. During this phase of operation, nuisance odors were controlled, but there was a persistant ammonia odor in the building and a foam problem in the ditches.

At the end of phase I, steps were taken for the purpose of controlling the foam and reducing the ammonia odor. These steps included; a) removal of 50 percent of the mixed liquor of the ditches, b) diluting the remainder with water from a nearby pond to a liquid level of approximately thirteen inches, c) raising the rotors so the immersion depth would be approximately six inches, and d) an addition of 500-1000 gallons of seed from the pilot oxidation ditch at Cornell University.

The results of this action were anticipated to be; a) reduction of the ammonia nitrogen concentration, BOD, and COD of the system by approximately three to four times, b) reduction in the ammonia concentration would reduce any inhibition to nitrification. With the lower COD and more efficient biomass, the oxygen demand would be reduced to a point at which a residual dissolved oxygen level might be maintained in the ditches, and c) with residual dissolved oxygen and the seed from the pilot plant oxidation ditch, nitrification could begin.

After these steps were taken, the ditches were put back into operation. Phase II consisted of the remaining 268 days of the study. The performance of the ditches has been evaluated for a one year period, January 1972 through December 1972. The nitrogen transformation and losses are summarized in the following sections.

Foaming was a problem throughout the twelve month study and was controlled by the addition of approximately two quarts of used motor oil to the ditches per day. The ammonia odor varied in strength but was usually present in the building.

Due to the large amount of leakage from the dew-drop watering system at the Houghton operation, a portion of the mixed liquor in the ditches had to be removed three to five times a week to maintain a relatively constant liquid level. Better water control would have reduced the frequency of mixed liquor removal and would have increased the mixed liquor solids concentration. Mass balances were prepared on the oxidation ditches to determine the percent reduction of total solids, total volatile solids, ash, total Kjeldahl nitrogen, ammonia nitrogen, organic nitrogen, NO_2-N,

NO_3-N, and COD. The mass balances considered the amount of these parameters entering the oxidation ditches, changes in their concentration in the mixed liquor, and the amount of the parameter in the mixed liquor that was withdrawn from the ditches for disposal. The loss of ammonia nitrogen due to ammonia stripping was not included in the mass balance of ammonia nitrogen since it could not be properly assessed. The samples of mixed liquor removed for analysis were not included in the mass balances since they represented a fraction of a percent of the mixed liquor withdrawn for disposal.

Monthly mass balances were calculated for February through December 1972. Due to a change in operation in early April, the calculations for April represented only the last 23 days of that month. The percent reduction of any of the above parameters represents the amount of that parameter that could not be accounted for in the mass balance. The mass balance for any of the above parameters can be represented by the following:

$$\text{Input} - (\pm \Delta\ \text{Storage}) - \text{Output} = \Delta\ \text{Parameter}$$

where Input - raw waste entering the oxidation ditches

Storage - accumulated bottom deposits and the change in concentration in the mixed liquor

Output - amount in mixed liquor be withdrawn from oxidation ditches

Δ Parameter - the change in the parameter

The change in parameters due to storage is primarily due to a change in mixed liquor concentration and the accumulation and compaction of materials on the bottom of the ditches. The mixed liquor concentration of the above parameters was determined by sampling and analysis. The change in storage was calculated over the monthly periods. The bottom accumulations were not sampled and analyzed throughout the study, but were measured and analyzed for total solids, total volatile solids and ash after 14 months (432 days) of the start-up of the ditches. By measuring the depth of the bottom deposits, the volume of the bottom deposits were calculated and from the analysis of the deposits, the daily accumulation of total solids, total volatile and ash were estimated. Since ammonia nitrogen is soluble, it was assumed that it would have the same concentration in the liquid of the bottom deposits as in the mixed liquor. The output represented only that amount of a parameter that was in the mixed liquor being removed from the oxidation ditches for final disposal on land.

ii) Mixed liquor characteristics - The mixed liquor of both ditches was sampled and analyzed periodically throughout the study period.

Because the two ditches received the same loadings, were roughly the same size, and were interconnected, the characteristics of both ditches were comparable. The solids and nitrogen data for ditch II are presented in Figures 44 and 45 and the nitrogen data for ditch I is presented in Figure 46. The variations noted in the Figures are due to the variations in ditch operation such as removal of about 50% of the mixed liquor on day 78, variations in the amounts of mixed liquor removed each week, variability of water added by the leaky waterers, and variations in microbial activity.

The nitrogen concentrations exhibited greater variations than did the solids concentrations. Oxidized nitrogen forms were rarely found. Nitrites were found only during one period of the study. No nitrates were found during the study.

iii) Process efficiency - From the results of raw waste, mixed liquor, and bottom deposit analysis, monthly mass balances were obtained on both oxidation ditches for total solids, total volatile solids, total Kjeldahl nitrogen, organic nitrogen and COD. The percent reduction of solids and nitrogen are shown in Figure 47.

Total Kjeldahl nitrogen losses from the oxidation ditches could have occurred by nitrification and ammonia volatilization. Table 23 indicates the total Kjeldahl nitrogen loading to the system, and the amount lost in terms of kilograms and as a percentage of the input.

Dissolved oxygen levels in the oxidation ditches ranged from a low of zero mg/l to a high of 8 mg/l. In each ditch, dissolved oxygen measurements were taken at six points (Figure 48) over a period of 13 months. During this period, the D.O. measurements were made on an average of twice a week. Table 24 shows the dissolved oxygen level at various points in the ditch as a percent of the measurements made. The dissolved oxygen level in the ditches was less than 1 mg/l for approximately 65-70 percent of the time and for approximately 70 percent of the ditch length.

The oxygen uptake rates of the mixed liquor in each ditch were estimated. The range of uptake rates was from 38 to 620 mg/l-hr. If one eliminates the extremes, the range of uptake rates was from approximately 100 to 400 mg/l-hr. These rates were determined in the laboratory and not in the oxidation ditches. Higher than expected oxygen uptake rates occurred in the ditches. At no time after start-up of the operation was dissolved oxygen consistently observed throughout the entire length of these ditches.

Shortly after the start-up, ammonia began to be released from the ditches in the vicinity of the rotors. The high ammonia concentration in the mixed liquor resulted from the incapacity of the rotor to add enough oxygen to sustain nitrification.

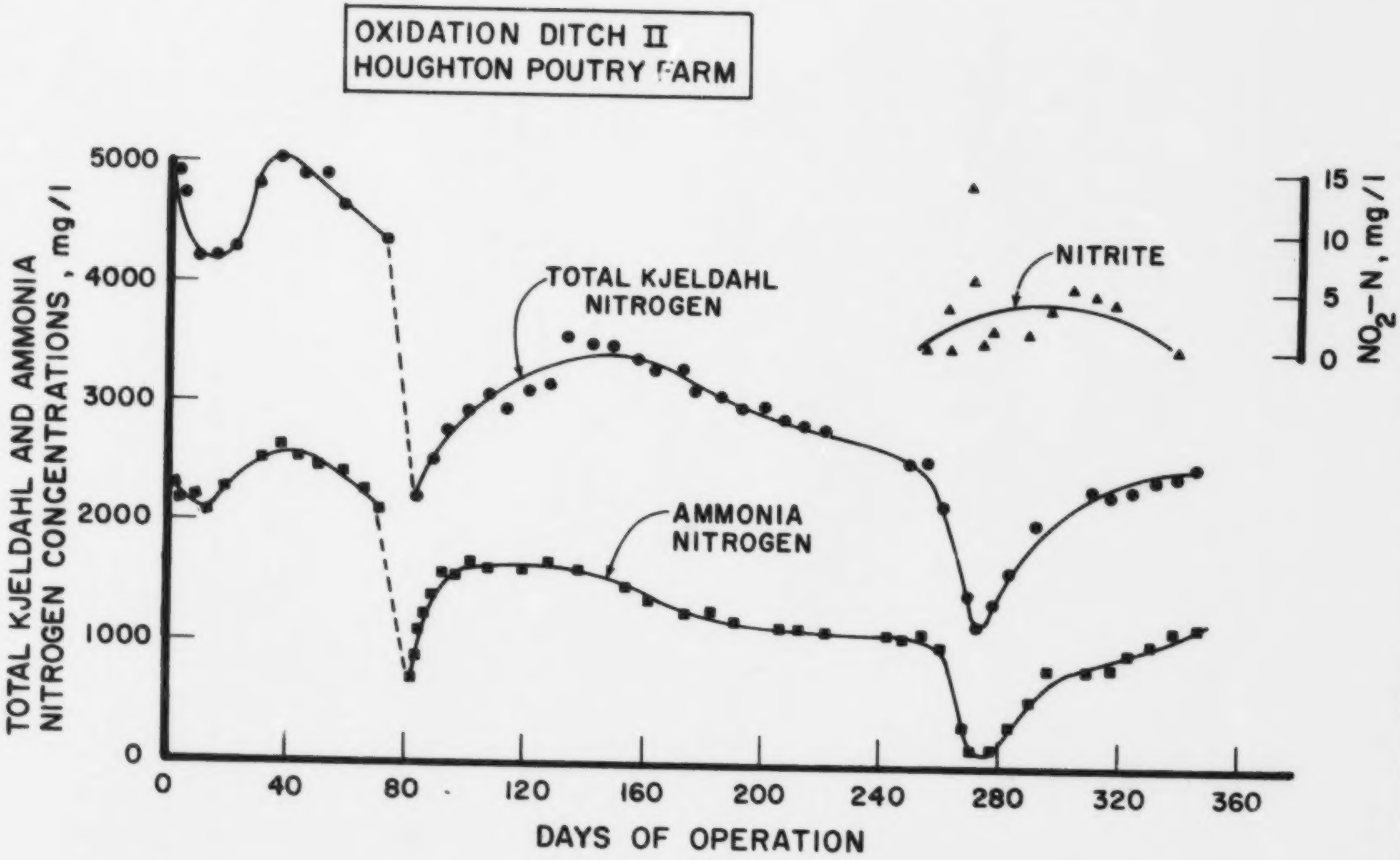


Figure 44. Nitrogen content of ODML in ditch II at Houghton poultry farm.

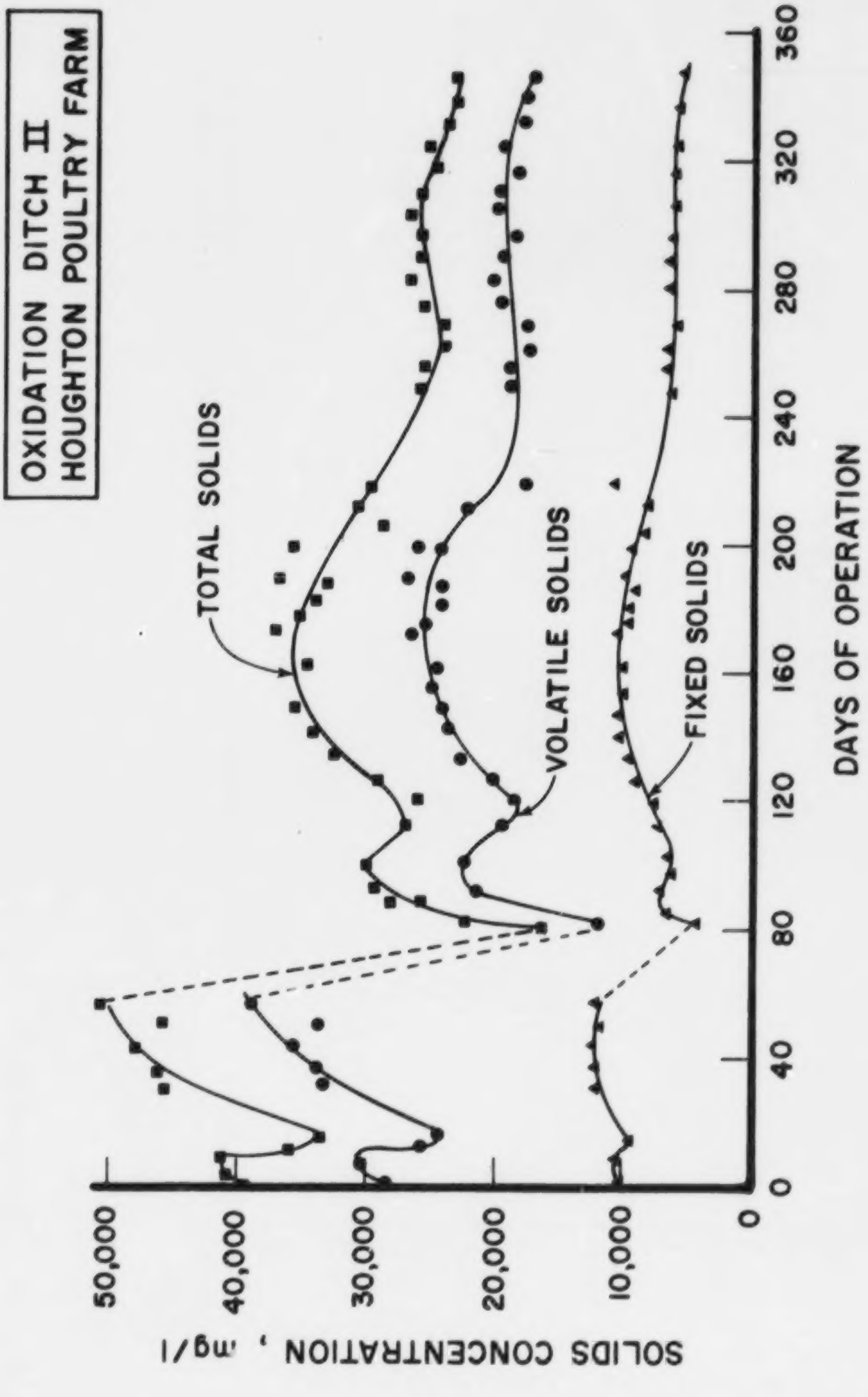


Figure 45. Solids content of ODML at the Houghton poultry farm.

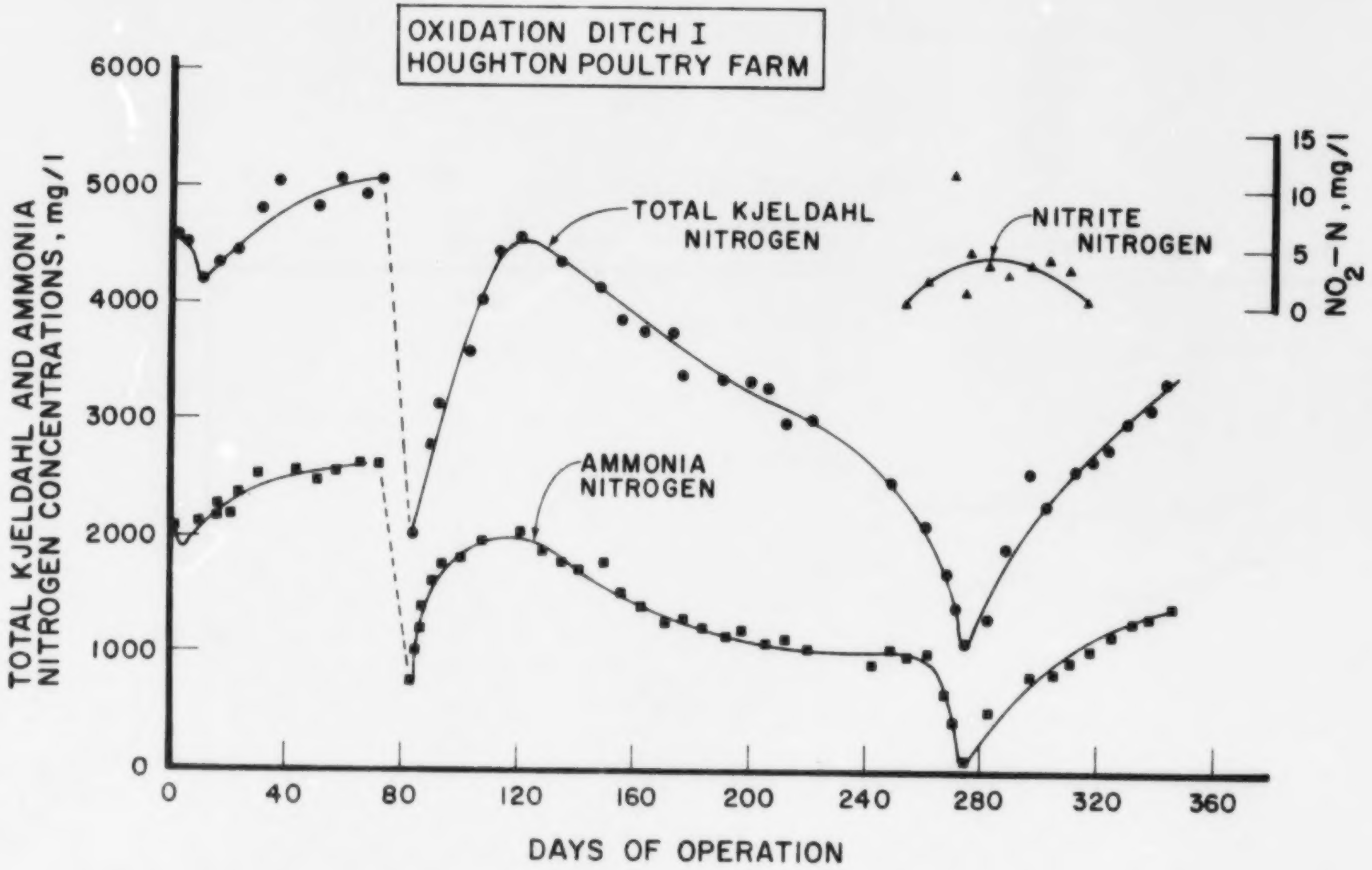


Figure 46. Nitrogen content of ODML in ditch I at Houghton poultry farm.

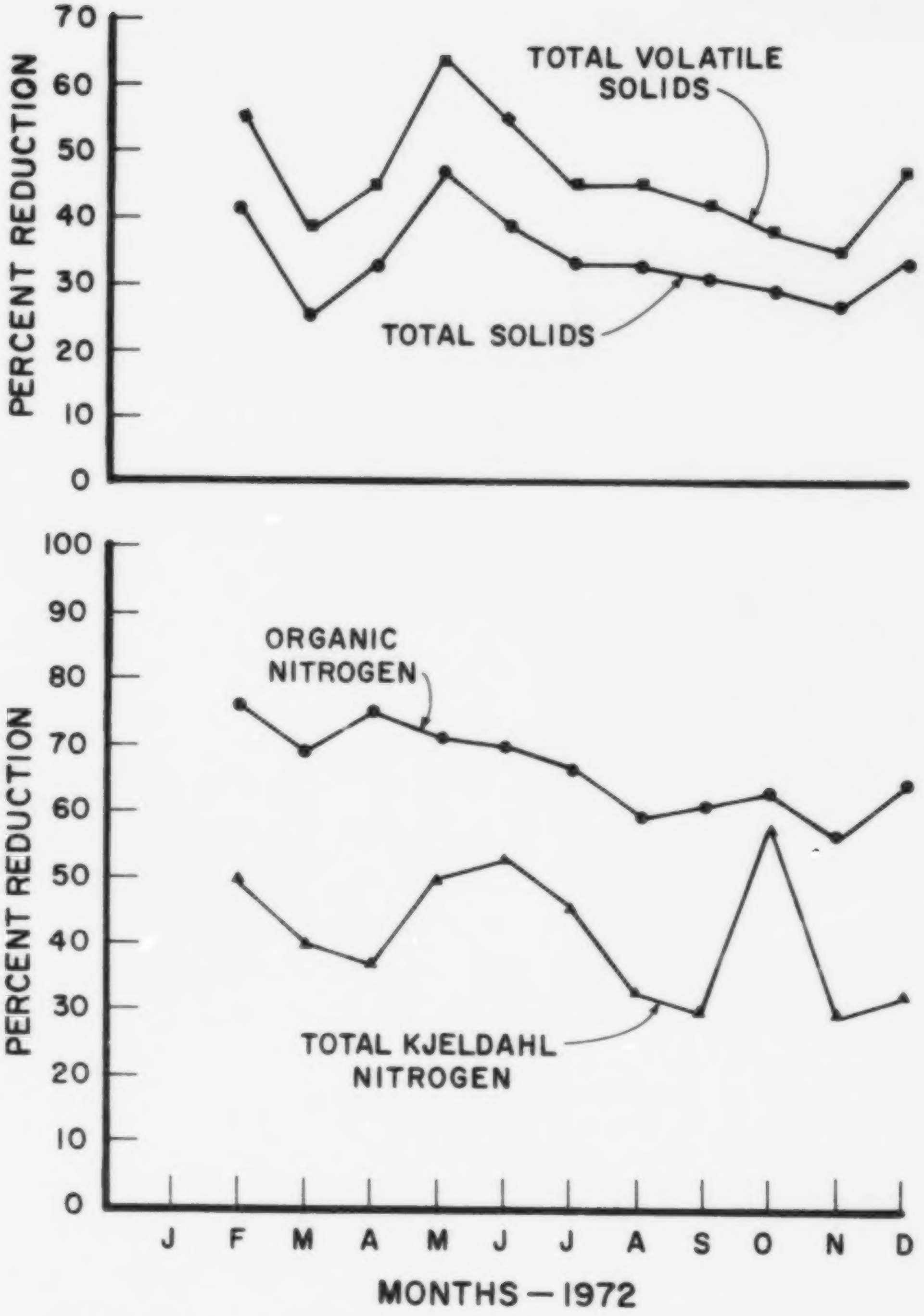


Figure 47. Efficiency of treatment at Houghton poultry farm during different months of 1972.

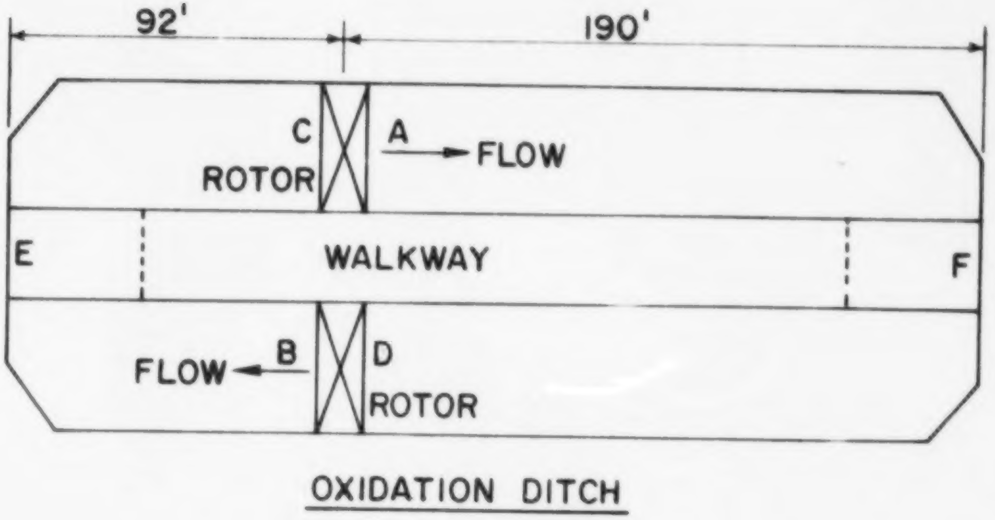

92'
190'
C
ROTOR
A
FLOW
E
WALKWAY
F
FLOW
B
D
ROTOR
OXIDATION DITCH

Figure 48. Dissolved oxygen sampling points in the Houghton oxidation ditches.

Table 23. TOTAL NITROGEN LOSS FROM OXIDATION DITCHES

Month	TKN loading (kg)	TKN loss* (kg)	% loss
February	1249	635	49
March	1370	547	40
April	1012	375	37
May	1203	601	50
June	1388	736	53
July	1422	655	46
August	1410	466	33
September	1357	407	30
October	1344	780	58
November	1395	405	29
December	1430	457	32

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*The TKN reduction represents the amount of total Kjeldahl nitrogen that could not be accounted for in the mass balance of the system.

Table 24. DISSOLVED OXYGEN LEVELS AT DIFFERENT POINTS IN HOUGHTON OXIDATION DITCHES

Sampling point	Range of the dissolved oxygen concentrations (mg/l)				
	>3	2-3	1-2	0<1	0
	Frequency of occurance of dissolved oxygen concentration ranges noted				
Ditch I					
A	21	29	45	5	0
B	13	25	47	15	0
C	9	0	12	23	56
D	0	6	6	27	61
E	7	7	17	45	24
F	7	5	4	33	51
Ditch II					
A	23	26	49	2	0
B	15	33	50	2	0
C	0	10	7	24	59
D	0	0	10	10	80
E	4	11	21	46	15
F	0	8	13	33	46

The pH of the mixed liquor varied only slightly. Microbial activity was high consisting primarily of bacteria and free swimming ciliates. No stalked ciliates or rotifers were found, indicating that a high degree of stabilization of the waste was not accomplished.

There were a number of factors that may have affected the treatment efficiency of the oxidation ditches at the Houghton Farm. These include dissolved oxygen, temperature, and the detention time of the mixed liquor. Due to the lack of control over the system, any effect temperature or dissolved oxygen had on the treatment efficiency were not detected or able to be determined.

The level of dissolved oxygen in the Houghton oxidation ditches was less than 2 mg/l 50 percent of the time, and 70 percent of the ditch had a dissolved oxygen concentration of less than 1 mg/l approximately 64 percent of the time. Therefore, the treatment efficiency of this system may have been adversely affected by inadequate dissolved oxygen.

An increase or decrease in temperature of a biological system will respectively increase or decrease the efficiency of the bacteria if other factors are held constant. The wide scattering of data shown in Figures 44-46 implies that other factors may have had a greater effect on treatment efficiency than the effects of temperature.

The factor that affected treatment efficiency the most was the mixed liquor detention time. This varied due to inability to control the input of water from the leaky waterers. The detention time has a direct effect on the efficiency of a treatment system. In each case, the trend was that with a decrease in detention time, the percent reduction or treatment efficiency was reduced (Figure 49). The lower efficiency in the removal of solids, nitrogen, and COD that was caused by a reduction in detention time was due to a number of factors. With a shorter detention time, the microbial population would have to be increased. This increase in size of the microbial population could only take place if there was the opportunity for solids separation and recycle. These oxidation ditches did not have this capacity. An increase in microbial efficiency could have occurred if the type of substrate could have been changed or the temperature increased. Neither of these factors could be controlled in these oxidation ditches.

iv) Loss of Nitrogen - A reduction in mixed liquor detention time affects the reduction of total nitrogen in the same manner as the other parameters. Total nitrogen was removed from the system by two processes, nitrification-denitrification (biologically) and ammonia volatilization (physically). For an efficient nitrification-denitrification process to be established while decreasing the detention time, the system would have to provide enough oxygen to develop a large nitrifying microbial population. As

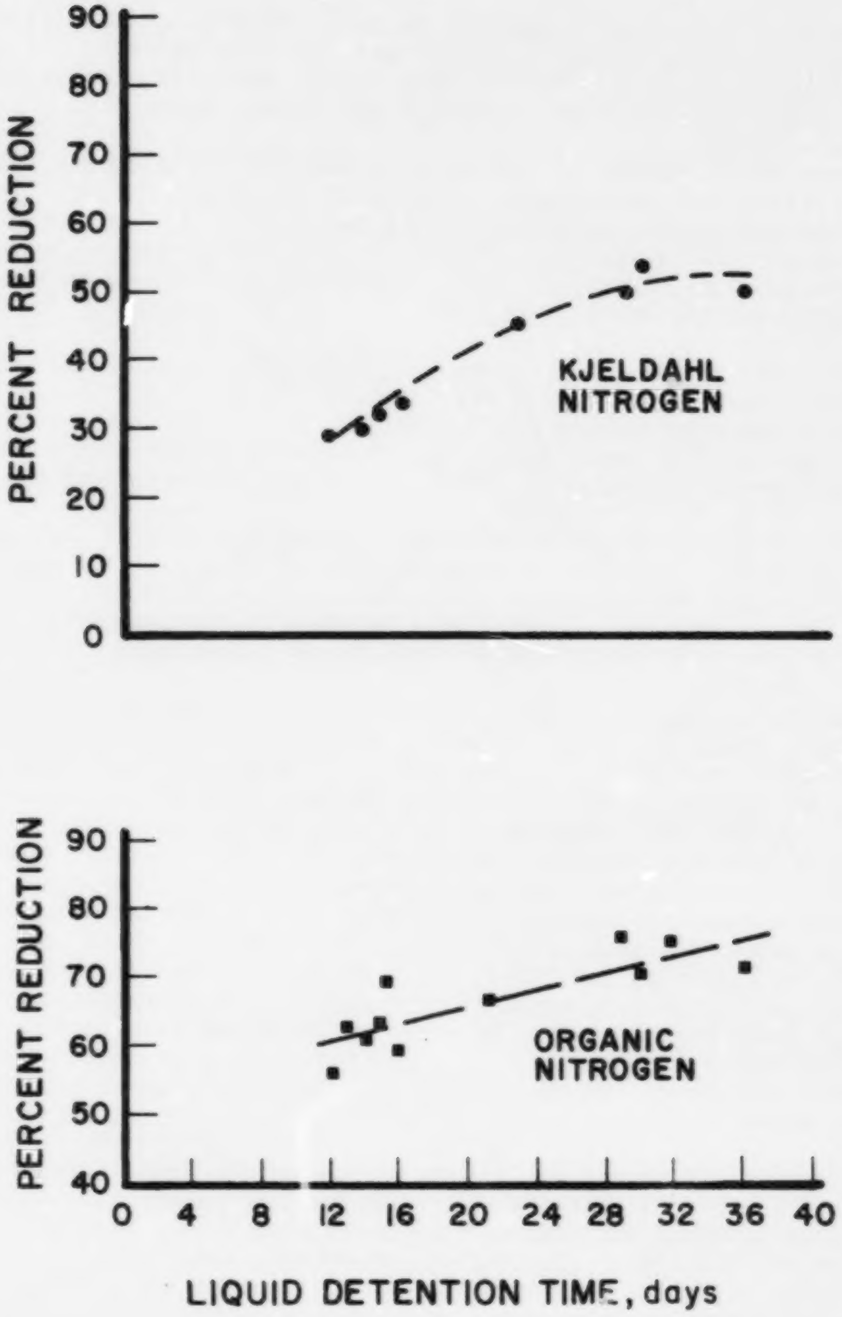

Figure 49. Effect of liquid detention time on nitrogen removal.

discussed above, the Houghton system was oxygen limiting and therefore, as detention times were decreased, nitrification opportunities decreased. The nitrifying population undoubtedly remained low due to the low dissolved oxygen concentrations.

The average loss of total Kjeldahl nitrogen in the Houghton oxidation ditches system was 42 percent. This percentage represents the amount of total nitrogen completely lost from the system. The total Kjeldahl nitrogen loss was approximately equivalent to total nitrogen loss since the amounts of nitrites and nitrates in the mixed liquor were negligible. In a system where nitrification is taking place without denitrification, the percent of total Kjeldahl nitrogen change would be greater than that of total nitrogen.

In the Houghton system, since there was an ammonia odor in the building and traces of nitrites were found in the mixed liquor, the process of ammonia volatilization and perhaps some nitrification followed by denitrification were responsible for the observed loss of total nitrogen. In both of these processes, the removal of total nitrogen depends on the hydrolysis of organic nitrogen to ammonia-nitrogen. The organic nitrogen hydrolysis to ammonia nitrogen remained fairly constant and averaged approximately 65 percent. This indicates that the highest average percent loss of total nitrogen by the two processes mentioned above could be at best 65 percent. The loss of total nitrogen from the waste handling system reached a high of 58 percent in October 1972.

Theoretical calculations were made to determine the role of ammonia volatilization in the removal of total nitrogen using procedures developed in the previous report (38). When some nitrification did occur in October 1972, the ammonia loss due to volatilization was approximately 8.5 percent based on the equations developed earlier. However, about 83 percent of the ammonia nitrogen in October was nitrified. Since there were only small amount of nitrites in the ditches, it can be surmised that the process of denitrification also was taking place. Obviously the proper conditions for an efficient nitrification-denitrification process were established in the Houghton oxidation ditches in October and possibly in the other months of operation.

Two factors that may have contributed to a more efficient nitrification-denitrification process have been discussed previously: temperature and detention time. In general, treatment efficiency decreased with a decrease in detention time. In October the detention time was the second shortest during the eleven month sampling period. The effect of temperature on this sytem could not be determined from the data, but in general, in a biological system, the efficiency will be greater at higher temperature. The average temperature for October was the third lowest during the study period. These facts suggest that neither temperature or detention time were the controlling factors that produced an efficient nitrification-denitrification process in October.

A third factor is the availability of oxygen for nitrification to occur. In an oxygen limiting system, the efficiency of nitrification would control the overall efficiency of nitrification-denitrification. During October the dissolved oxygen concentrations in the mixed liquor was greater than zero mg/l throughout the ditches for three out of the four sampling dates. With the higher dissolved oxygen levels, the oxygen input was greater than the demand and nitrification could be obtained. At the same time, reduced conditions within portions of the ditches did occur and resulted in denitrification. For at least one sampling date each month, dissolved oxygen levels throughout the oxidation ditches for the months of February, May, June, and July were also greater than zero. The ammonia-nitrogen loss during these months was greater than that for March, November, or December for which there was no evidence of dissolved oxygen concentration being greater than zero throughout the ditches.

The availability of oxygen for nitrification in October can be inferred from two additional factors. First, the concentration of all parameters in the mixed liquor were at their lowest except for April, and temperatures were fairly low, both of which would increase oxygen transfer. Second, the percent reduction of COD was the lowest in the eleven months. This would mean that the oxygen demand for oxidizing organic matter was at its lowest. Both of these conditions would increase the amount of oxygen available for nitrification. The increased amount of oxygen available to the system was the primary reason for the increase in nitrification during October.

GENERAL DISCUSSION

The bench scale and pilot plant studies reported herein on the biological treatment of poultry wastewater have confirmed the previously observed nitrogen losses under aerobic conditions (>1 mg of DO/1) and provided information on the circumstances under which these occurred.

Similar nitrogen losses are known to occur in sewage treatment plants, lakes, and other aquatic ecosystems presumably under aerobic conditions (40, 41, 42). The losses of nitrogen could be due to ammonia volatilization and denitrification of the oxidized forms of nitrogen into gaseous end products. A knowledge of the conditions that control these losses would be useful for designing and operating a treatment system, such as the oxidation ditch for nitrogen control in addition to preventing malodors.

Nitrogen Losses Due to Ammonia Volatilization

The degree of ammonia volatilization from a system depends on the a) concentration of NH_4^+-N, b) pH; losses being greater in the alkaline range particularly above pH 9, and c) degree of aeration. Everything being equal, losses of ammonia increase with an increase in temperature. During the start-up of oxidation ditches for treating poultry wastewaters, the conditions for ammonia volatilization are at their optimum. During the start-up phase relatively large concentrations of NH_4^+-N are available due to deamination of the organic nitrogen contained in the poultry wastewater. The pH of mixed liquor suspensions at this time (during start-up) is generally in the range of 8.0-9.0, which facilitates the formation of free ammonia. This ammonia can be removed by the aeration provided by the rotor in the oxidation ditch.

In the oxidation ditch at the Houghton Farm, odor control was achieved, but the aeration was not adequate throughout the ditch to sustain nitrification. The result was the occurrence of a large concentration of NH_4^+-N (>2000 mg/l) in the mixed liquor and a pH within the range of 8.0-8.5. Although it was not possible to evaluate the losses of nitrogen due to ammonia volatilization by a mass balance approach, it could be predicted by the equations developed in another study (38). These losses were approximately 8.5% of the total nitrogen input into the ditch. In the pilot plant oxidation ditch, these losses were 7.5% and occurred during the start-up phase of the ditch when nitrification was not yet established.

Observations revealed that relatively larger amounts of ammonia were lost near the rotor of the Houghton Farm as evidenced by the conspicuous ammonia odor near it in contrast to the absence of such an odor elsewhere in the poultry house. A similar observation was made in another oxidation ditch located in Manorcrest Farms, Camillus, N.Y. This is plausible since greater agitation of the mixed liquor occurred near the rotor and hence more ammonia stripping at the rotor than at any other location in the ditch.

In view of the operational results of the oxidation ditch, it appears that if perceptable nitrification has to be sustained, adequate aeration of the mixed liquor should be provided to maintain a dissolved oxygen concentration of ≈2 mg/l. This will not only help decrease free ammonia that generally occurs in the start-up phase, which may be toxic to the nitrifying organisms, but also maintain the needed supply of oxygen for their growth.

Nitrogen Losses Due to Denitrification Under Aerobic Conditions

In the pilot plant oxidation ditch, nitrification was established after the initial start-up phase. As a result of this nitrification, the pH of the mixed liquor dropped below neutrality. Under these conditions, losses of nitrogen due to ammonia volatilization were negligible since all the ammonia was in the ionic form. Nevertheless, a materials balance on nitrogen indicated that about 25% of the nitrogen entering the ditch was lost from the systems. These losses could be attributed to the dissimilatory utilization of nitrite and nitrate for the respiratory activity of the microorganisms in the mixed liquor under seemingly aerobic conditions. This observation suggests that if nitrogen removal from manures is contemplated as one of the goals, it can perhaps be optimized in the ditch by increasing the probability of the oxidized nitrogen species to be utilized as the electron acceptors without significantly disrupting the process of nitrification. Two ways of increasing this probability and thereby increasing the losses of nitrogen are a) reducing the dissolved oxygen concentration in the ditch, and b) increasing the hydrogen donating ability of the mixed liquor. Since the latter can not be changed easily, because the input of manure per day is relatively constant, the parameter that can be changed is the dissolved oxygen concentration in the mixed liquor, which can be achieved by turning off the rotor periodically.

This hypothesis has been verified in bench scale units at various loading rates and oxygen inputs to the mixed liquor. The results of these studies have shown that correspondingly higher losses of oxidized nitrogen occurred as the loading rates were increased and oxygen inputs decreased until dissolved oxygen became a limiting factor in the reactors (Table 18). When dissolved oxygen became limiting, nitrification ceased and accumulation of NH_4^+-N resulted with an increase in the pH of the mixed liquor to about 8.5, thus providing conditions conducive for ammonia volatilization. Although nitrification ceased under these conditions, it could be reestablished by aerating the mixed liquor to maintain a dissolved oxygen concentration of >1 mg/l, confirming earlier observations (38).

With the increase in the loading rate, nitrogen losses increased under aerobic conditions because of an increase in the oxygen uptake rate of the mixed liquor. The increased suspended solids concentration may also have impeded the transfer of oxygen to the microbial flocs, thus providing a greater probability for the NO_2^- and NO_3^- to be utilized as the electron acceptors. Thus while maintaining nitrification in a mixed liquor, an increase in the loss of nitrogen by denitrification can be expected when the oxygen uptake rate of a mixed liquor is increased by increasing the loading rate. Conversely, if it is desired to minimize nitrogen losses, and thereby conserve nitrogen, the treatment system can be designed such that the aeration devices are sized to provide sufficient aeration in order to minimize the probability of the utilization of NO_2^- and NO_3^- as electron acceptors at the expense of the dissolved oxygen.

Another factor that seems to influence the losses of nitrogen in a treatment system, such as the oxidation ditch, is mixing. When the rotor was stopped in a nitrifying oxidation ditch, the concentration of nitrates decreased from 780 mg/l to 260 mg/l in about a week and remained constant at this level for an additional week at which time the rotor was turned on for about 30 minutes to provide mixing. In about five hours the NO_3^--N decreased from a concentration of 250 mg/l to 110 mg/l. The rates of denitrification under quiescent and mixing conditions were 3.1 mg/l/hr and 28 mg/l/hr. Prior to the mixing of oxidation ditch mixed liquor, a blanket of sludge was noted at the bottom of the ditch, with a clear supernatant. Since the oxidized nitrogen species are soluble and no intimate mixing was occurring between the settled solids and the supernatant, the NO_2^- and NO_3^- remained in the supernatant and no odorous conditions existed in the poultry house. When mixing was provided for 30 minutes, the NO_2^- and NO_3^- in the supernatant came in contact with the anaerobic sludge at the bottom and rapid denitrification took place as evidenced by the higher denitrification rates. Such high denitrification may not be observed in actual practice using in-situ denitrification with continuous mixing since the conditions used in this study were different and a sludge that settled for more than a week was brought into contact with the supernatant. Although an odor of hydrogen sulfide was noticed initially, it quickly subsided during the mixing period. The very low denitrification rates under quiescent conditions and the odorless conditions that existed during the in-situ denitrification of the mixed liquor may perhaps enable the storage of nitrified waste for relatively longer periods of time. The storage period may even be prolonged in winter time, since the denitrification rates will be even lower than in the spring and summer. This enables the poultry farmer to store nitrified manure suspensions in a separate storage tank during winter under relatively odorless conditions for extended periods without hindering the performance of the oxidation ditch.

SECTION VI

LAND APPLICATION AND CROP RESPONSE TO TREATED POULTRY MANURE

INTRODUCTION

There has been increasing concern on the part of commercial poultrymen and the general public regarding odors and pollution of streams and lakes resulting from the land disposal of poultry manure. This problem has been accentuated in recent years with the increasing number of birds in a given poultry operation. Since the land is the utlimate disposal medium for most of this product, available land area should be increased in proportion to the number of birds per given poultry operation. Rural development has resulted in low tolerance on the part of the public regarding offensive odors and water pollution from agriculture. It is essential to improve the handling and disposal of poultry manure. Several methods of aerobically treating poultry wastes to control odors have been investigated at the Cornell Agricultural Waste Management Laboratory.

It has been established that the aerobic treatment of animal wastes can alter the kinds and amounts of various inorganic nitrogen fractions in the material. It has not been determined how well these aerobically treated materials will serve as plant nutrients after application to the soil nor is their potential as water pollutants known.

Greenhouse and field studies were designed to study the behavior of aerobically treated poultry manure. Manures from the different treatment processes were compared with untreated manure. Initially, the quantities of various aerobically treated wastes were limited. This necessitated greenhouse experiments to evaluate the behavior of the various wastes as sources of plant nutrients. These greenhouse experiments also provided the opportunity to compare the effect of different soil pH values on the plant availability of the various N compounds in the manure. The pollution potential of these manures was determined by measuring runoff throughout the growing season. Runoff from field plots was collected and analyzed for nitrogen and phosphorus compounds.

In addition to direct economic benefits, properly utilized poultry manure applied to the land will help avoid undue nutrient enrichment of water courses. This same proper utilization of poultry manure will also help avoid the urgent need to seek new sources of plant nutrients. Such new sources of nutrients might be most demanding in terms of energy consumption.

Research is needed to study the response of field crops to manure addition It is necessary to determine optimum rates and optimum periods of application. Poultrymen realize that the nutrient content of chicken manure can be very high relative to cattle manure and yield response studies with poultry manure are especially important to producers. For those poultrymen with inadequate acreage for disposal, maximum rates without crop damage is most important. The majority of poultrymen need to determine the optimum amount to apply to significantly increase crop yields. This is especially true for corn.

The objectives of the studies reported here were:

1. Determine the effect of soil pH on corn response in the greenhouse when extremely different rates of aerobically treated poultry manures are applied to the soil.

2. To evaluate the effect of soil pH on inorganic nitrogen transformations in the soil following the application of aerobically treated manures.

3. Determine the rate, form and time of manure application permissible without causing pollution of runoff waters as determined by collections from surface runoff plots.

4. Determine maximum rate of application of poultry manure to which corn will produce a yield response in a single application or in cumulative applications over a period of years.

5. Determine to the extent possible through soil and plant tissue testing the fate of nitrogen and other nutrients introduced to the soil through land application of poultry wastes at various rates, forms and times of application.

6. Evaluate potential or Orchard and Brome grass meadows for utilization of poultry manure as a fertilizer.

7. Determine optimum treatment systems for poultry wastes applied to field crops.

REVIEW OF LITERATURE

The value of poultry manure for crop production has long been recognized. (53) It is a matter of record that such manures improve soil physical condition and soil productivity. (54,55,56)

In terms of poultry manure utilization the major questions are rate of application and also possible water pollution from such manure application.

Recently Loehr and his associates have demonstrated that phosphorus, ammonia, and nitrogen can be removed from poultry manure by advanced waste treatment. (38) It then becomes a practical question of water pollution control and management to learn how much this advanced waste treatment will decrease runoff water contents for nitrogen and phosphorus under a system of land disposal.

Nitrogen compounds found in poultry manure will undoubtedly go through the same transformations as have recently been shown to be important in fertilizer applications. (57-58) Between soil pHs of 7-8 these transformations may involve the build up of nitrous acid compounds which are known to be toxic to corn plants. In this study such compounds have been observed in greenhouse studies on corn when poultry manure has been applied to the soil.

Organic wastes and sludges are known to have a stimulating influence on crop growth. (59-60) Ascorbic acid, carotene, tryptophane, tyrosine, and similar compounds are, supposedly, the sources of these sludge growth promoting substances. It would seem reasonable to suppose that poultry manures would generate similar growth promoting substances.

METHODS AND MATERIALS

Three greenhouse studies were conducted to determine the effect of different rates of aerobically treated poultry manure on corn growth and nitrogen transformations in the soil. Soil pH affects were also studied. Several soils important in Northeast crop production were used.

Three field studies were established for the purpose of determining nitrogen balances in corn plants, perennial forages, and the soil. The effects of poultry manure sources and application rates on surface runoff and corn yields were also studied.

Greenhouse Experiment I

Nitrogen Transformations in the Soil From Aerobically Treated Poultry Manure --

This greenhouse study was conducted to determine the effect of different rates of aerobically treated poultry waste on corn response and nitrogen transformations in the soil. Two soils developed from glacial till, Honeoye silt loam pH 7.1 and Mardin silt loam 4.2, were used. These soils were selected because of their importance to Northeastern agriculture. Poultry manure sources that were used were the following: oxidation ditch manure which was material that had been aerated by passing the contents of a 324 cubic foot ditch through a mechanical surface aerator; stored oxidation ditch manure which was oxidation ditch manure that had been stored after treatment in a holding tank under reducing conditions for 9 months; diffused air manure previously aerated by bubbling air through the slurry of a ditch similar in size to the oxidation ditch; and raw manure taken from a poultry house where manure had accumulated below the poultry cages for 3 months and to which litter had not been added. The different aeration treatments brought about a change in the kinds and amounts of nitrogen compounds present in the various manures. The amount of the four major nitrogen sources in the various manure are presented in Table 25.

Table 25. AMOUNT OF EACH N FRACTION AT TIME OF APPLICATION CONTAINED IN UNTREATED AND TREATED FORMS OF POULTRY MANURE (GREENHOUSE EXPERIMENT I).

Initial composition	Stored Oxidation ditch manure	Oxidation ditch manure	Diffused Air manure	Raw manure
Organic N	83	49	35	32
NH_4^+ -N	17	14	65	68
NO_2^- -N	0	35	0	0
NO_3-N	0	2	0	0

Manure was applied to each soil at rates that would provide 0, 168, 247, 694, and 1389 kg N/ha soil from the raw manure. All other manures were applied at rates of 0, 280, 560, 1120 and 2240 kg N/ha. Each greenhouse pot contained about 3000 grams of soil. Each treatment was replicated four times. Each pot was sampled at three different times during the experiment and analyzed for the different inorganic nitrogen sources listed in Table 25 and also for total soil nitrogen.

The differences in percent of nitrogen fraction noted in Table 25 can be explained by the fact that approximately 2/3 of the N in raw manure exists as NH_4-N. Diffused air treated manure was very similar since the treatment did little oxidation. By way of contrast the oxidation ditch manure was effectively oxidized -- at least to the NO_2-N stage. Proportional amounts of stable organic nitrogen were increased. When oxidation ditch manure was stored, denitrification apparently eliminated the NO_2-N.

Greenhouse Experiment II

Corn Response on Two Soils From Different Rates of Treated Poultry Manure as Influenced by pH --

Observations made in the first greenhouse experiment suggested that the availability of nitrogen from manure to corn and/or leaching could be significantly affected by the soil pH. The soils used in the first experiment were used again with the Mardin soil of pH 4.2 being limed to achieve additional pH levels of 5, 7 and 7.2.

Three manures were used: manure treated with diffused air; oxidation ditch manure and raw manure. These materials were applied to both soils at the rates of 0, 280, 560 and 1120 kg N/ha soil. The N content of the various manures at time of application is presented in Table 26.

It can be noted that the percentage values for the several nitrogen compounds in the various manure sources are somewhat different from those reported in Table 25. The nitrogen compounds present depend on the state of the biological environment and organisms present at the time of sampling. The oxidation ditch material for Greenhouse Experiment II was obtained from a 15,000 bird commercial operation. Oxidation ditch manure used in Greenhouse Experiment I came from the Animal Waste Laboratory on the Cornell campus. Thus, differences in the kinds and amounts of nitrogeneous compounds can and do occur with different operations of a given treatment system. No residual of dissolved oxygen in the oxidation ditch slurry and a higher total solids content can result in the presence only of organic and ammonium N.

Table 26. AMOUNT OF EACH N FRACTION AT TIME OF APPLICATION CONTAINED IN UNTREATED AND TREATED FORMS OF POULTRY MANURE. (GREENHOUSE EXPERIMENT II).

Initial Composition	Oxidation Ditch	Diffused Air	Raw Manure
Organic N	46	52	18
NH_4^--N	54	0	82
NO_2^--N	0	46	0
NO_3^--N	0	22	0

Again, each treatment was replicated four times and corn was grown for 42 days. Each pot was sampled three times during the growing period. The samples were analyzed for inorganic soil nitrogen and total soil nitrogen.

Greenhouse Exp III

Corn Response and Nitrogen Uptake From Soils Receiving Various Rates of Oxidation Ditch and Raw Manure --

The purpose of this study was to determine corn response, nitrogen uptake and the behavior of nitrogen compounds in raw and oxidation ditch manure when applied to soils in the greenhouse. The soils used were taken from areas adjacent to field studies where poultry manure was being applied for crop response and runoff studies. These locations were the Aurora Research Farm (Honeoye soil pH 7.1) and Ithaca Poultry Farm (Collamer soil pH 7.2). This greenhouse study provided the opportunity of comparing greenhouse and field results with corn using the same soils and manure sources.

Rates of nitrogen applied from the two manure sources were 0, 112, and 224 kg N/ha. However it should be noted that the fresh manure application was based on previous analyses which were 1% total nitrogen. Subsequent analysis of this material established the total nitrogen as 1.36%. The applied rates were in fact 152 and 304 instead of 112 and 224 kg N/ha.

In addition a chemical fertilizer treatment of 448 kg/ha of 20-10-10 fertilizer was included as one of the treatments. Corn was then planted in soil which was in eleven quart plastic pails serving as greenhouse containers. Each pail contained about 10 kg of soil.

The plants were harvested 80 days after planting. Silking had occurred. Fresh weight and dry weight were determined. Laboratory analysis for TKN, was carried out on the plant materials produced in the greenhouse.

Poultry Waste Residue Field Study

Corn Yield Response to Poultry Manure in the Year of Application and Subsequent Residual Effects --

A field study was initiated in 1971 and was concluded in the fall of 1973. It was established at the Aurora Research Farm on a high lime soil pH 7.0, a Honeoye silt loam. The object of this test was to study and determine the balance of nitrogen in the corn plant and in the soil in order that fertilization and manuring practices can be regulated to result in the least water pollution with economic corn production. In addition, it provided the opportunity to compare manure with commercial fertilizer as a source of N.

Untreated poultry manure was applied at rates of 0, 56, 112, 224, 448 and 896 kg N/ha. A seventh treatment consisted of commercial fertilizer at the rate of 22.4 kg/ha each of nitrogen, phosphate and potash. Corn was grown and harvested.

In 1972, the original plots of this field study were split and the same treatments repeated on one-half the original plots. Corn was again grown on both halves of these field plots. This permitted a measurement of residual effects of manure applied in 1971 as well as the effects of a wide range in rates over two years. In the spring of 1973 the sub-plots which had received 112 and 448 kg N/ha from manure the two previous years were the only ones to receive additional manure. The chemical fertilizer treatment was also continued at an increased rate of 90-45-45 kg/ha of N, P, and K, respectively. See Fig. 50.

Surface Runoff Loss Field Studies

Effects of Land Applied Poultry Waste on Runoff Losses --

A field study was established in 1972 that would permit the collection of surface water runoff from plots that had received applications of poultry manure. The experiment was designed to permit the application of different rates of manure, 0, 112, and 224 kg N/ha, from different sources, oxidation ditch and fresh poultry manure (no litter), was applied to land for corn in both spring and fall applications.

	NITROGEN, kg / ha						
	POULTRY MANURE						CHEM FERT
	0	56	112	224	448	896	22
1971	0	56	112	224	448	896	22
	0	56	112	224	448	896	22
1972	0	0	0	0	0	0	0
	0	56	112	224	448	896	22

Figure 50. Nitrogen applied over a 2 year period as poultry manure or chemical fertilizer, poultry waste residue study, 1971-72.

Plots were established on a Collamer silt loam soil near the Poultry Farm at Ithaca. Several different degrees of slope ranging from 4-10% were utilized. The experimental area had been in a grass sod for many years prior to 1972. The chemical herbicides, atrazine and paraquat, were applied to the soil surface 5 days prior to plowing. Plowing was done within 2 days following application of the manure. Corn was planted May 22.

Individual plots measured 3.0 m by 9.1 m and were surrounded by lawn edging. At the base of the plot slope, collection troughs were installed that were connected to a flow divider which diverts one-twentieth of the entire amount of flow into a storage tank. Runoff water was then measured and analyzed for soluble orthophosphate, ammonium, nitrite, nitrate, total Kjeldahl nitrogen and total soluble phosphorus. Sediment samples were secured and analyzed for total phosphorus, total nitrogen and organic matter. Soil samples were taken at weekly intervals during the period May 25 - Aug 3 from both the surface, 0-30 cm, and subsurface 30-60 cm depth. Analysis included ammonium, nitrite, nitrate nitrogen and total kjeldahl nitrogen.

Poultry Waste on Grasses Field Study

Yield Response of Grasses to Poultry Manure --

An additional yield study was made to determine the response of bromegrass and orchardgrass to varying rates and different sources of poultry manure. Applications of poultry manure were made at rates of 0, 56, 112 and 224 kg/ha N for each of fresh manure and oxidation ditch manure. These treatments were applied both in the fall and in the spring. Commercial fertilizer, 56 kg N/ha was used as an additional treatment.

Poultry Waste at Extreme Rates

A further study was made in Sullivan County, which has a very dense poultry population, at the request of the county agent and in cooperation with the agent. The purpose of this study was to measure the effects of extremely high rates of poultry manure on yield and on the soil environment.

A field that had been in continuous corn for 5 years was selected. This small field was subdivided into fourteen plots. Each measured 11 x 44 meters (36 x 180 feet). One half of each plot (or 90 feet, 27.5 meters) on the uphill side had received 22 metric tons/ha (10 ton/acre) of cow manure the previous year. The remaining half of the plot had no cow manure. The design consisted of two randomized blocks. Within each block, each whole plot received one of seven rates of poultry manure at random. These rates were 0, 24, 68, 100, 200, 270 and 370 metric tons/ha (0, 15, 30, 45, 90, 120 and 165 ton/acre). The manure was from a pullet rearing house and the actual weight of manure applied to each plot was determined by weighing random loads of manure. Each load was made uniform and a composite manure sample was secured for analysis.

Upon application, the soil was plowed, fitted and planted to corn at an intended rate of 25,000 plants/acre. A starter fertilizer of 15-15-15 was used. Atrazine plus Lasso was applied for weed control. The plots are located on Lackawanna silt loam. Soil samples were taken before the addition of poultry manure but after the application of cow manure. Topsoil (0-25 cm, 0-10 in) and subsoil (25-50 cm, 10-20 in) samples were again taken in mid-July 1973 to study the difference in available nitrogen in each treatment.

RESULTS AND DISCUSSION

Greenhouse Experiment I

Some results of this study are presented in Figure 51 which summarizes all measurements for a given variable.

It is apparent that the corn grown on acid Mardin silt loam (4.2) out yielded the corn grown on neutral Honeoye silt loam by more than 100%. When one considers the source of nitrogen, raw poultry manure is inferior. In terms of rate of application 1120 kg/ha of nitrogen resulted in a yield decrease of corn produced in 36 days.

Fig. 52 and 53 show that NO_3-N and NO_2-N were the most available forms of nitrogen in the Honeoye soil (pH 7.2). However the most abundant form on the Mardin soil (pH 4.2) was NH_4-N. See Fig. 54. Although there was little or no NO_2-N and NO_3-N in the various manure sources when applied to the soil, the initial analysis after application showed various amounts present, especially in the Honeoye soil. The manure sources were mixed with the soil and the mixture allowed 5 days to dry. Sampling for analysis was done after drying. This amount of drying time apparently permitted the formation of NO_2-N and NO_3-N. Fig. 55 illustrates yield response curves for the various treatments. Maximum dry matter yields obtained on Honeoye and Mardin silt loam soil were 23 and 54 gms respectively, whereas check yields were 8 and 9 gms suggesting a strong soil-manure source interaction. No visual symptoms of nutrient deficiency were observed in plants from either soil. On the Honeoye soil, maximum rates of oxidation ditch (OD) and untreated or raw manure (R) greatly depressed corn yields.

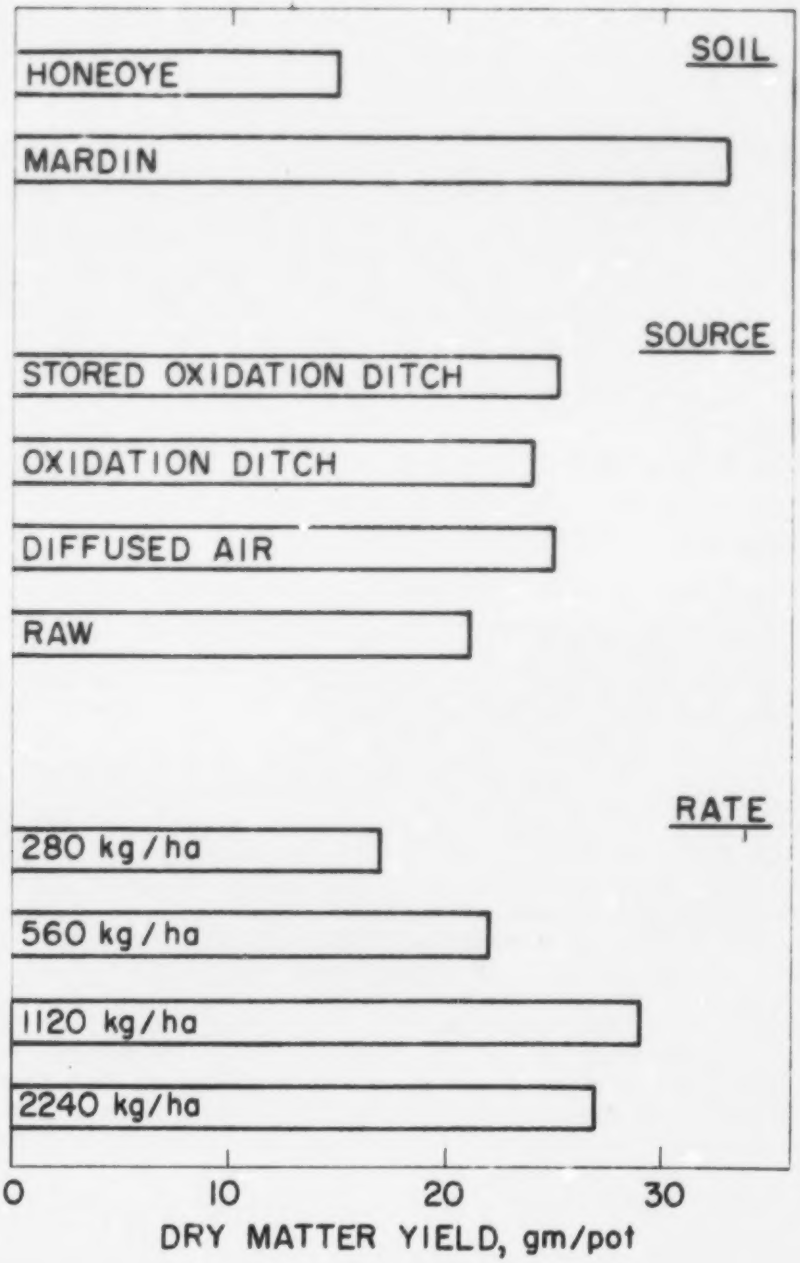

Figure 51. Corn dry matter yields as influenced by soil, manure source and rate of manure application. L.S.D. @ .01 = 1.7, 2.3 and 2.3 respectively.

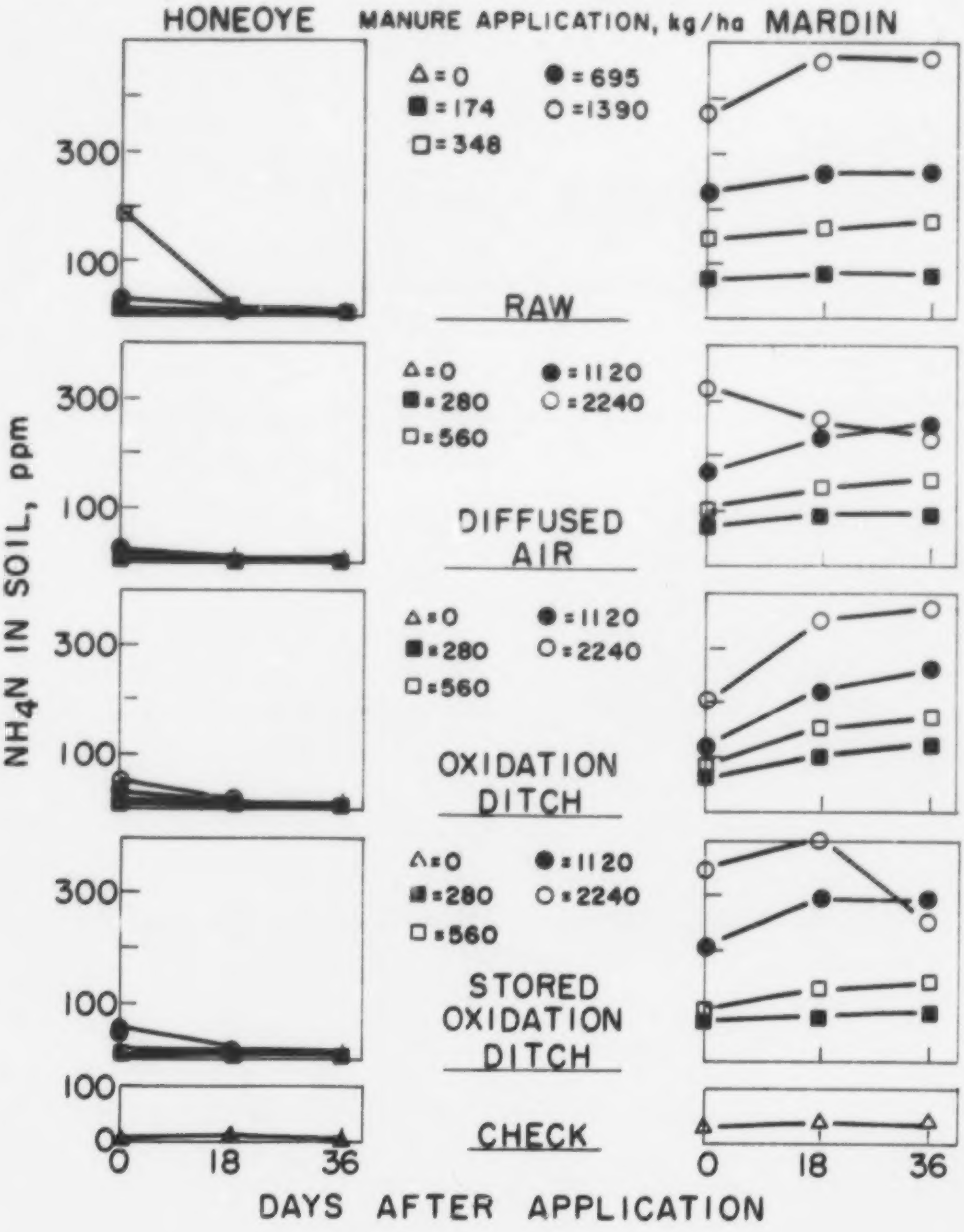

Figure 52. Average Honeoye and Mardin soil NO_3-N concentrations for each manure source and each sampling.

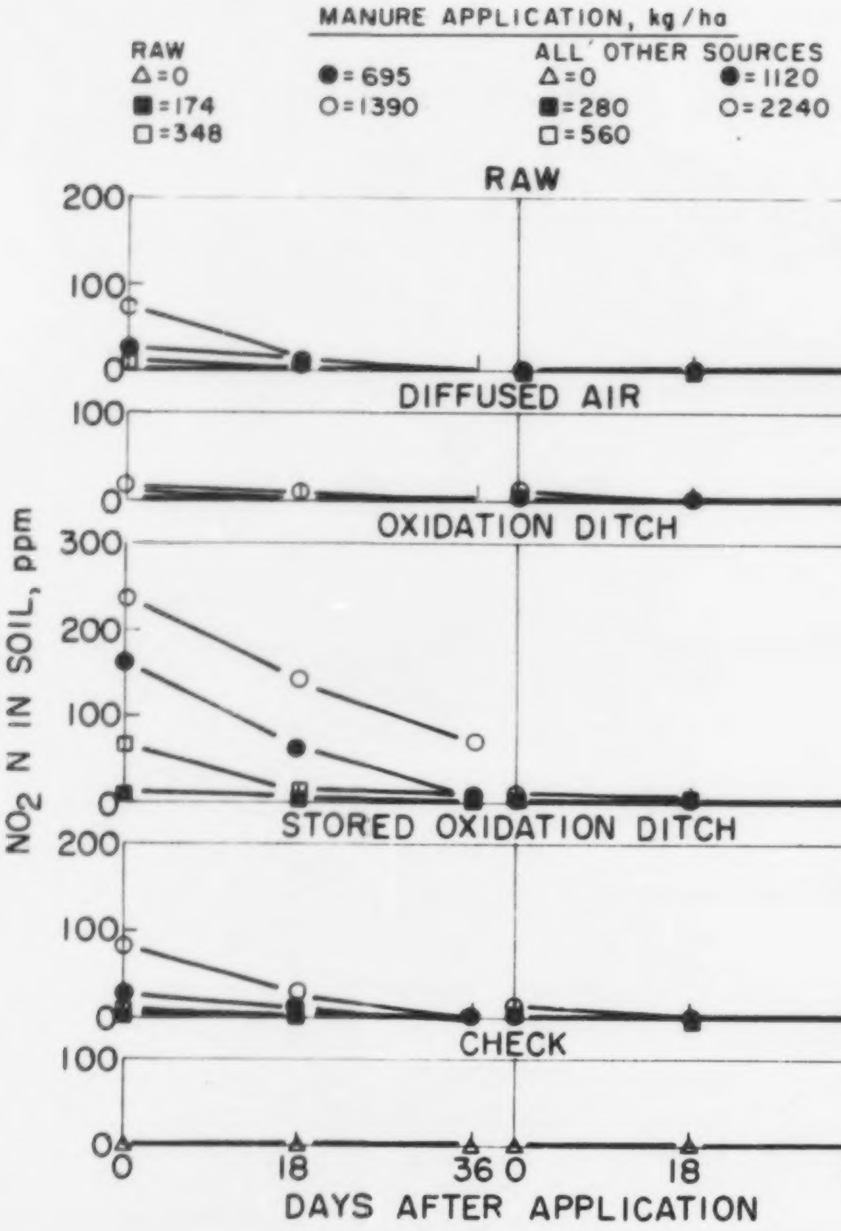

Figure 53. Average Honeoye and Mardin NO_2-N concentrations for each source at 3 sampling dates.

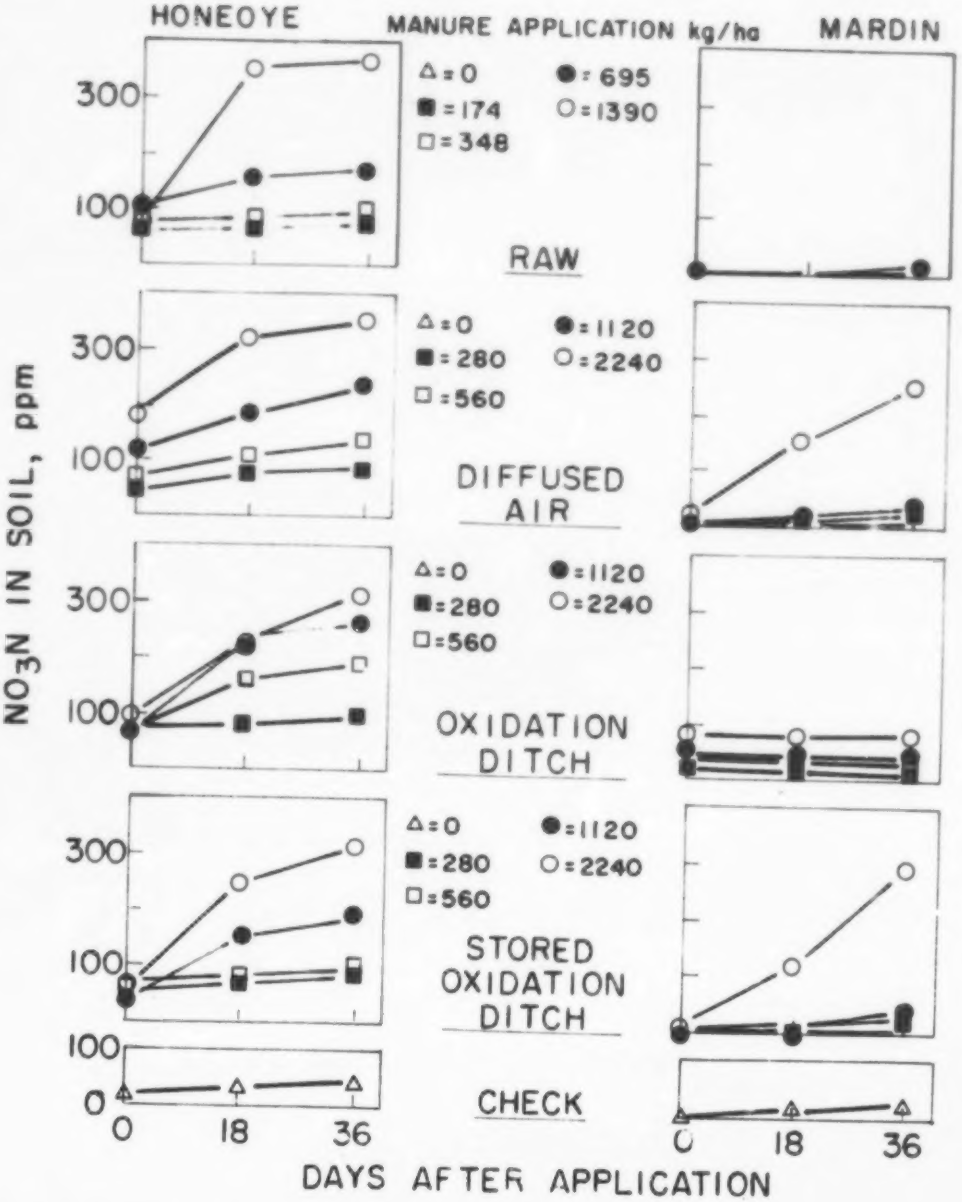

Figure 54. Average Honeoye and Mardin soil NH_4-N concentrations for each manure source at 3 sampling dates.

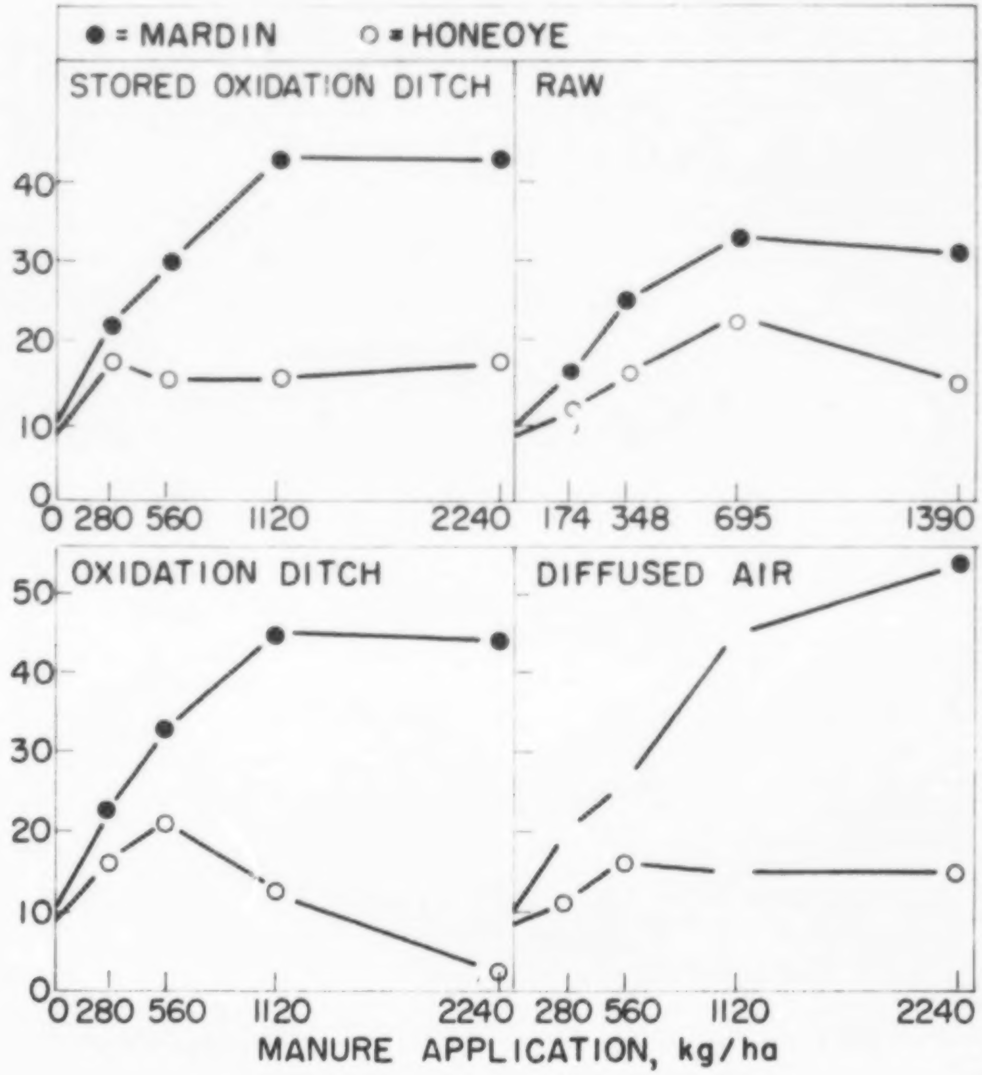

Figure 55. Effect of manure source and rate of application on corn yields after 36 days growth on Honeoye and Mardin silt loam soils.

Yield differences within the four treatment rates of stored oxidation ditch (SOD) and diffused air treated manures (DA) were not significant. On Mardin soil increasing rates of application gave yields as great or greater than those at the immediately lower rate.

Greenhouse Experiment II

Table 27 summarizes yield results and nitrogen contents from three levels of pH with the Mardin soil series and one level with the Honeoye series. It is apparent that six week dry matter production yields of corn grown on all soil situations are similar except for the Mardin series limed to pH 7.2. These yields are significantly lower. The nitrogen content of the plants is, however, significantly higher. (3.54%)

Table 27. DRY MATTER YIELDS AND NITROGEN CONTENT OF CORN GROWN ON 2 SOILS AND 3 pH LEVELS. (GREENHOUSE EXPERIMENT II).

Soil Series and pH	Yield in Grams per pot	Nitrogen Content % N
Mardin pH 4.2	20.3	1.92
Mardin pH 5.7	20.5	1.88
Mardin pH 7.2	11.1	3.54
Honeoye pH 7.1	19.6	1.95
	L.S.D 1.1	L.S.D. .11

Fig. 56 demonstrates that for all soils, as rates of application of nitrogen increase, corn dry matter yield per pot increased. Nitrogen contents of the corn plants also increased as the rate of nitrogen application increased. All of these differences were statistically significant.

Fig. 57 shows the interaction of soil treated at various pH values with varying rates of manure applications for all of the sources of manure. The most easily understood situation is the Mardin series

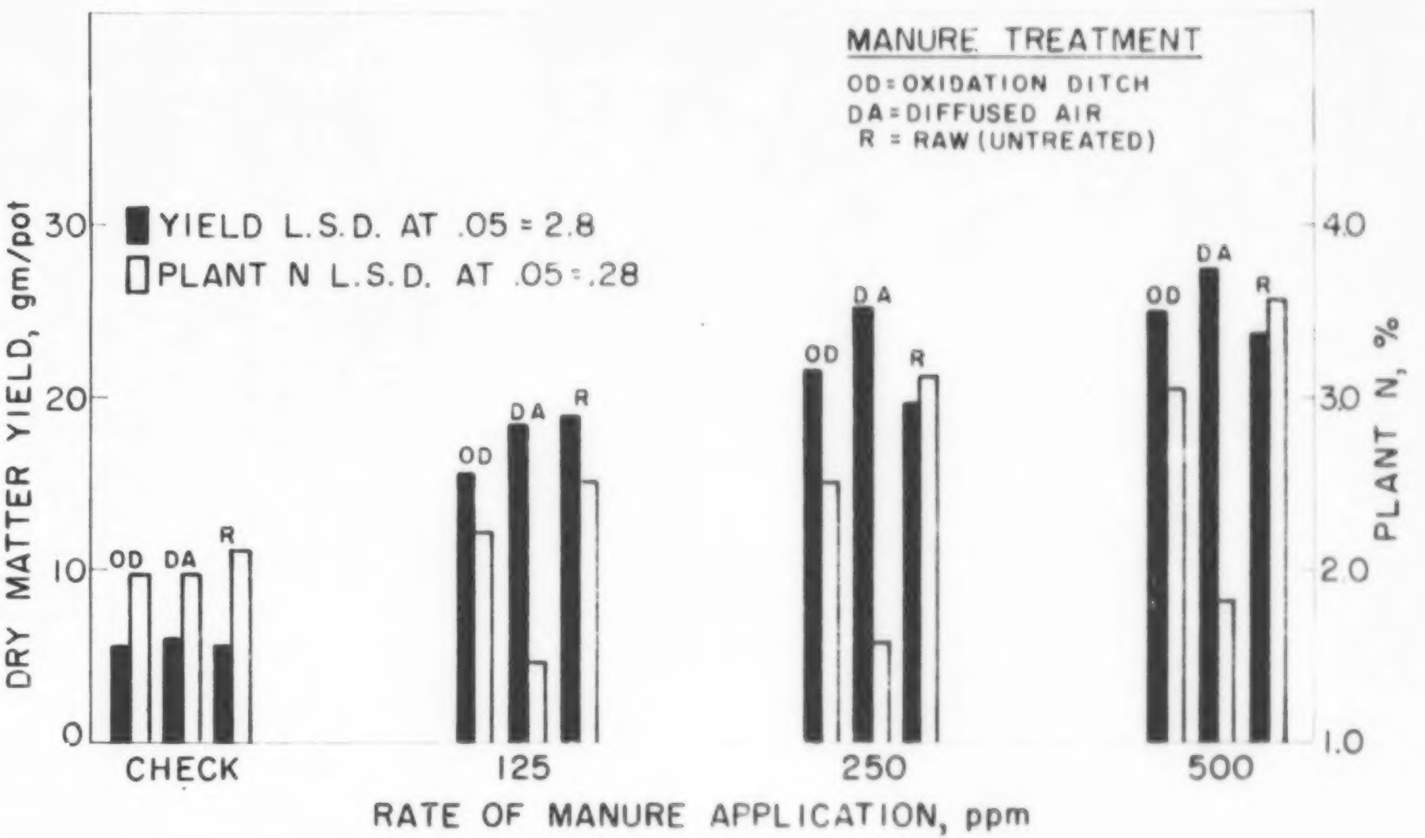

Figure 56. Source of manure nitrogen and rate of manure application in relation to dry matter produced and nitrogen content of corn plants. Greenhouse Exp. II.

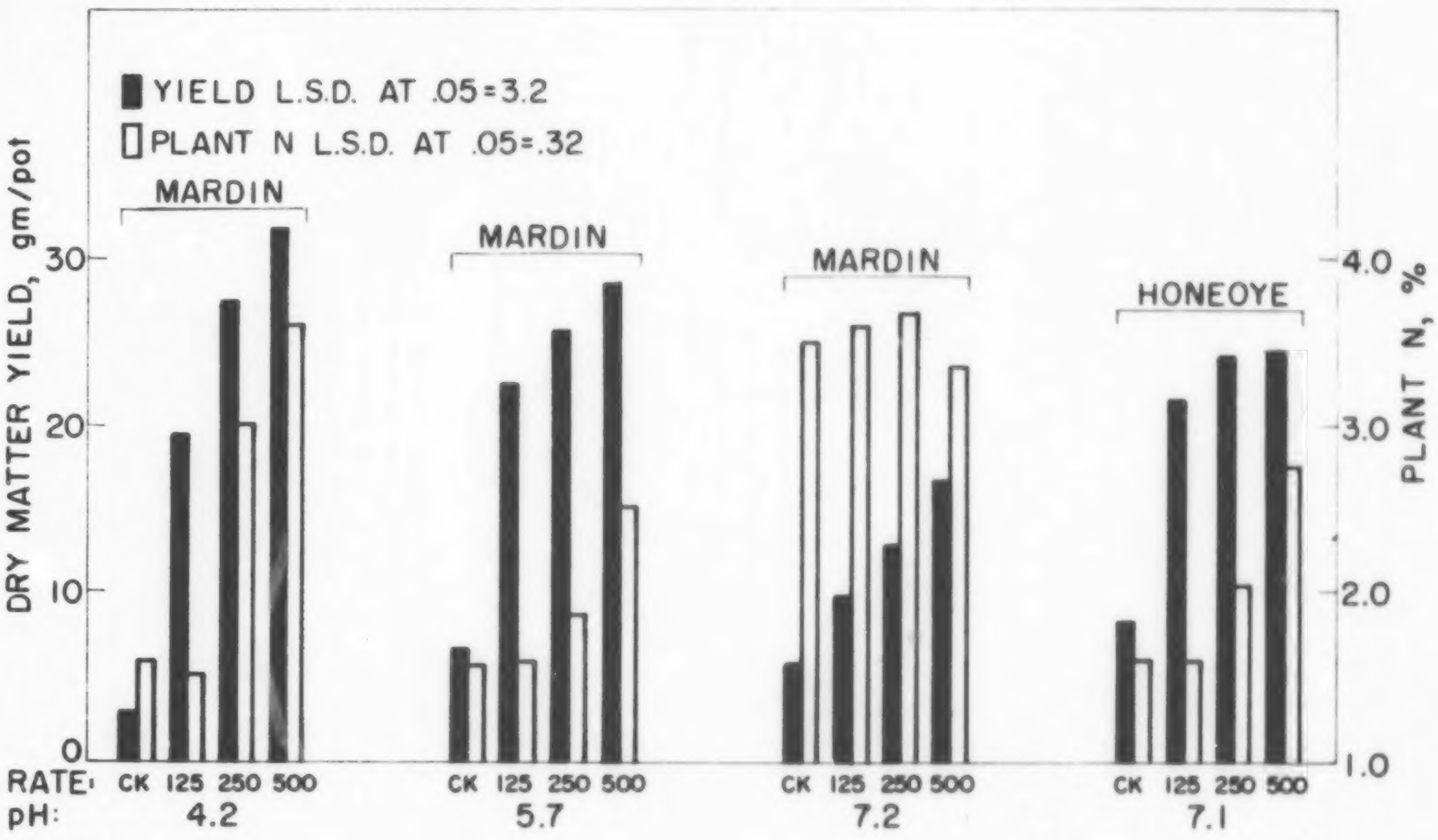

Figure 57. Soil pH and rate of N application (kg,ha) in relation to dry matter produced and nitrogen content of corn plants. Greenhouse Exp. II.

of soils with a pH of 4.2. Under this circumstance increments of added nitrogen from all of the various materials resulted in significantly higher yields of dry matter produced. There are corresponding increases in % of N with increased dry matter production. Growth response of the corn plants on Mardin silt loam at pH 5.7 and Honeoye silt loam at pH 7.1 are very similar. Differences between the growth produced by the check treatment and the 125 parts per million treatment of nitrogen are in the order of 15 grams per pot. Subsequent increments of nitrogen added to these two soils result in a much lower dry matter increment. These incremental yield increases in the case of the Honeoye silt loam are not significant statistically. In the case of the Mardin silt loam at pH 5.7 only the difference in dry matter produced by 125 parts per million as compared to 500 parts per million is significant.

The most unusual feature of this presentation is the exceedingly low yields of corn produced on the Mardin silt loam at pH 7.2. These low yields are associated with very high corn plant nitrogen contents. Recently it has been shown (57-58) that nitrates can become a problem in corn production. This is especially true when soil pH ranges between 7-8. The nature and extent of this toxicity has been discussed in literature cited above.

Fig. 58 shows the relation between the various treated poultry waste material and the soil used for greenhouse corn production. With the Mardin silt loam soil at pH 4.2 diffused air treated manure gave the highest dry matter yield. However, it did not significantly exceed the yield from the raw manure treated soil. It should be noted that the plant nitrogen content of the diffuse air manure was exceedingly low in all soil situations except under the circumstance of Mardin silt loam 7.2. The Honeoye silt pH 7.1 soil treated with diffused air poultry waste was intermediate in nitrogen content. However, it was one of the higher yielding treatments for the production of dry matter by corn plants.

Oxidation ditch treated manure and raw manure for the Mardin silt loam at pH 7.2 gave the lowest dry matter production. It is interesting that these two treatments also showed appreciable quantities of nitrite at the end of 21 days of corn growth. This was not true for any other treatments.

Fig. 59 and Fig. 60 show the NO_2-N in the soil treated with raw manure and oxidation ditch manure respectively. It should be noted that yield tends to increase as NO_2-N increases. This can be associated with the fact that as NO_2-N increases so does NO_3-N. The NO_3 values are not shown here. Since NO_3-N tends to stimulate growth and dry matter production, the toxic influence of quantities

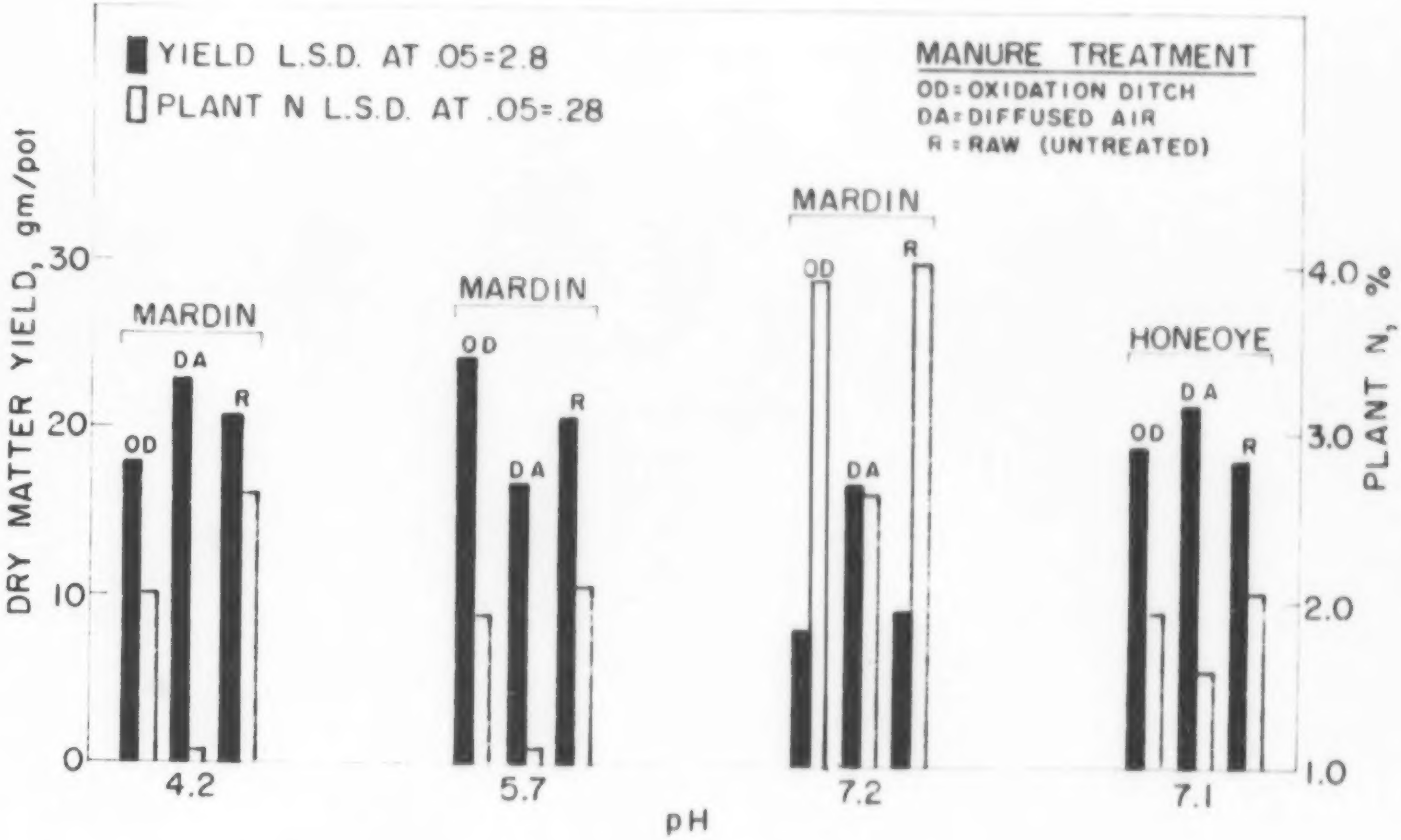

Figure 58. Soil pH and source of manure in relation to dry matter produced and nitrogen content of corn plants. Greenhouse Exp. II.

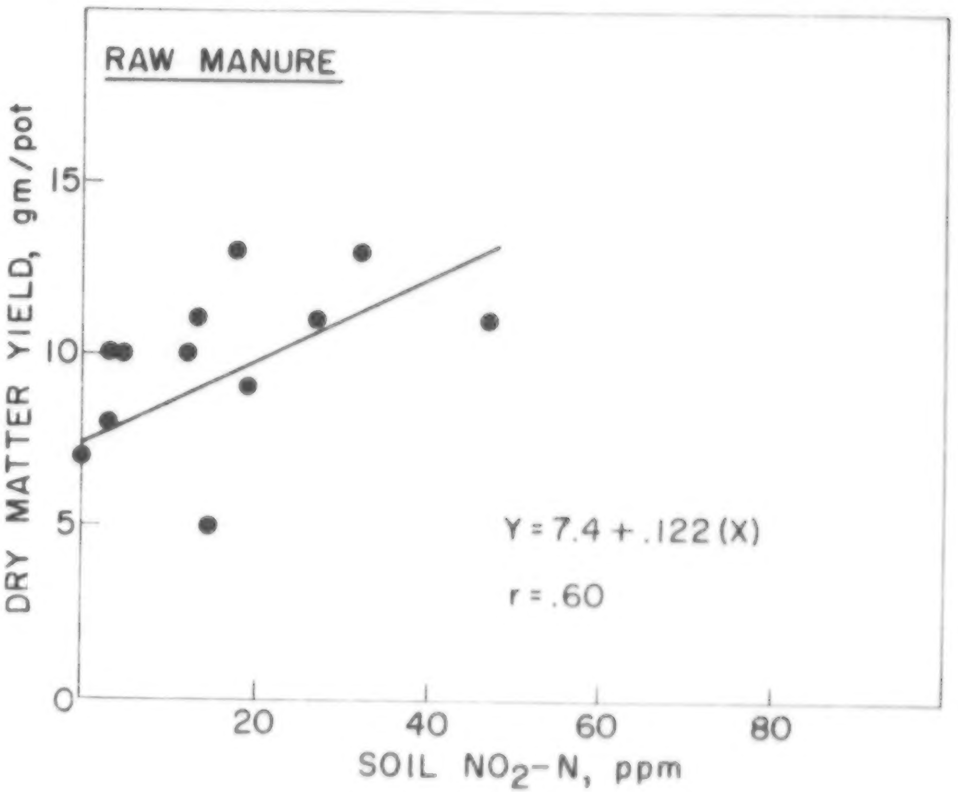

Figure 59. 42 day dry matter corn yields as influenced by soil NO_2-N from raw manure 21 days after planting.

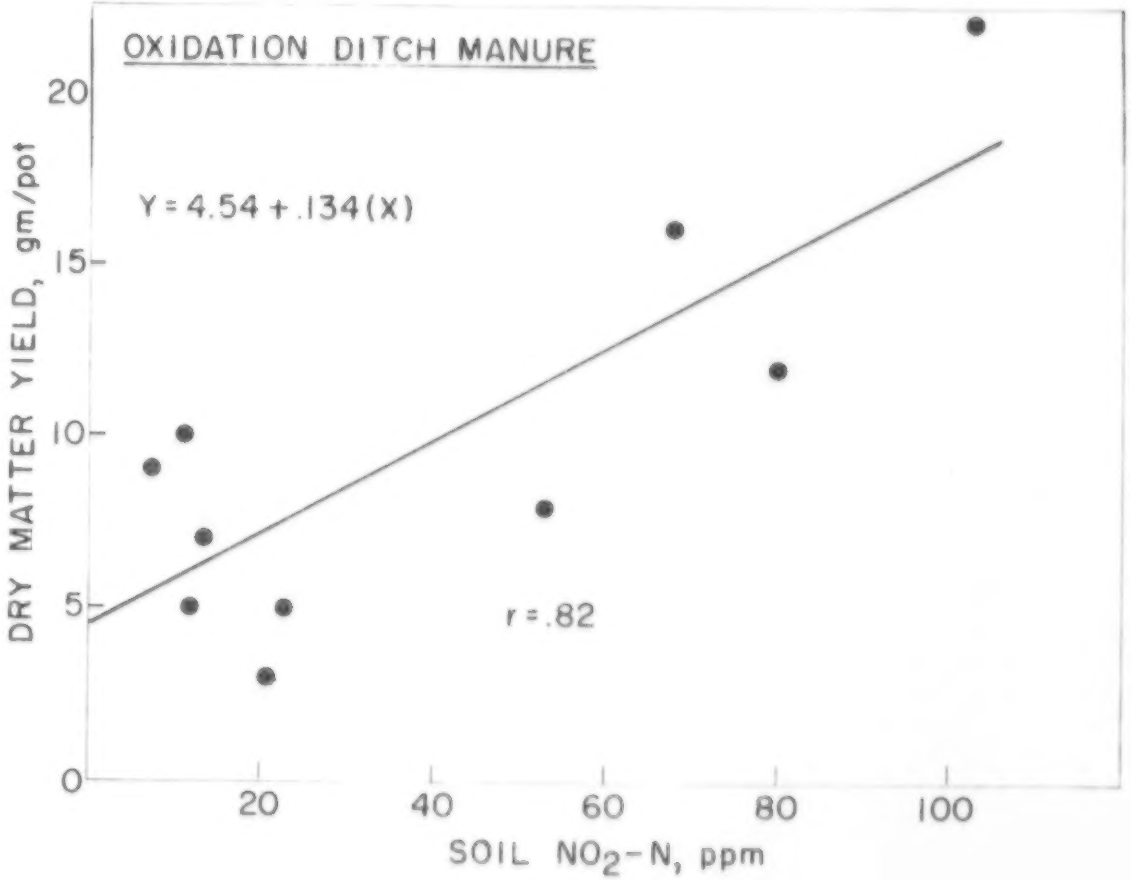

Figure 60. 42 day corn dry matter yields as influenced by soil NO_2-N from oxidation ditch manure 21 days after planting.

Fig. 61 indicates that corn dry matter yields increased with nitrogen levels up to 1,120 kg N/ha.

Greenhouse Exp III

Fig. 62 illustrates that soil #2, a Collamer silt loam provided a higher rate of nitrogen uptake per given unit of supposedly available nitrogen than did soil #1 which was a Honeoye Lima. This resulted in a higher dry matter production also as can be seen in Fig. 63. The uptake on both soils was in a straight line relationship in an upward direction, with the available soil N. There was a very high correlation between crop uptake and dry matter produced. It is interesting to note (in Fig. 62) the consistent relationship between treatments on both soils. Treatments 1 and 7 represent the same treatment on 2 different soils and are in the same relative position to the other treatments. This is true of all other treatments.

Table 28 shows that the Collamer silt loam (soil #2) had an initial soil N content that was approximately double that of the Honeoye silt loam (soil #1). An estimation of available N from the various sources was made as follows: 1/2 of 1% of the initial soil N + 50% of manure N or 100% of commercial fertilizer N. These estimates of N vailability in greenhouse studies are consistent with estimates by other investigators including Bouldin and Lathwell (45). Ninety kg/ha of commercial fertilizer nitrogen compared most favorably to 112 kg/ha of nitrogen applied as poultry manure in crop uptake and in dry matter of corn produced. This was regardless of soil. If as assumed 100% of the commercial fertilizer N was available and only 50% of the manure nitrogen was available this means that 56 kg/ha of manure nitrogen produced as much dry matter as 90 kg/ha of commercial fertilizer nitrogen. The implications would be that either a large percentage of the commercial nitrogen is being lost to the environment by denitrification or else it is not available in as desirable a form as from the manure N. The corn was watered in such a way as to prevent any loss from leaching.

POULTRY WASTE RESIDUE STUDY

It can be seen in Fig. 64 that shelled corn yields in 1971 increased from 5830 to 6773 kg/ha with increasing N rates from manure of 0 to 224 kg/ha. Applications of N from manure above 224 kg/ha resulted in yield reductions. The highest dry matter stover yields in 1971 from manure as an N source was obtained at the 224 kg/ha rate, Fig. 65. The range in stover yields was 2176 to 2979 kg/ha with the highest yield

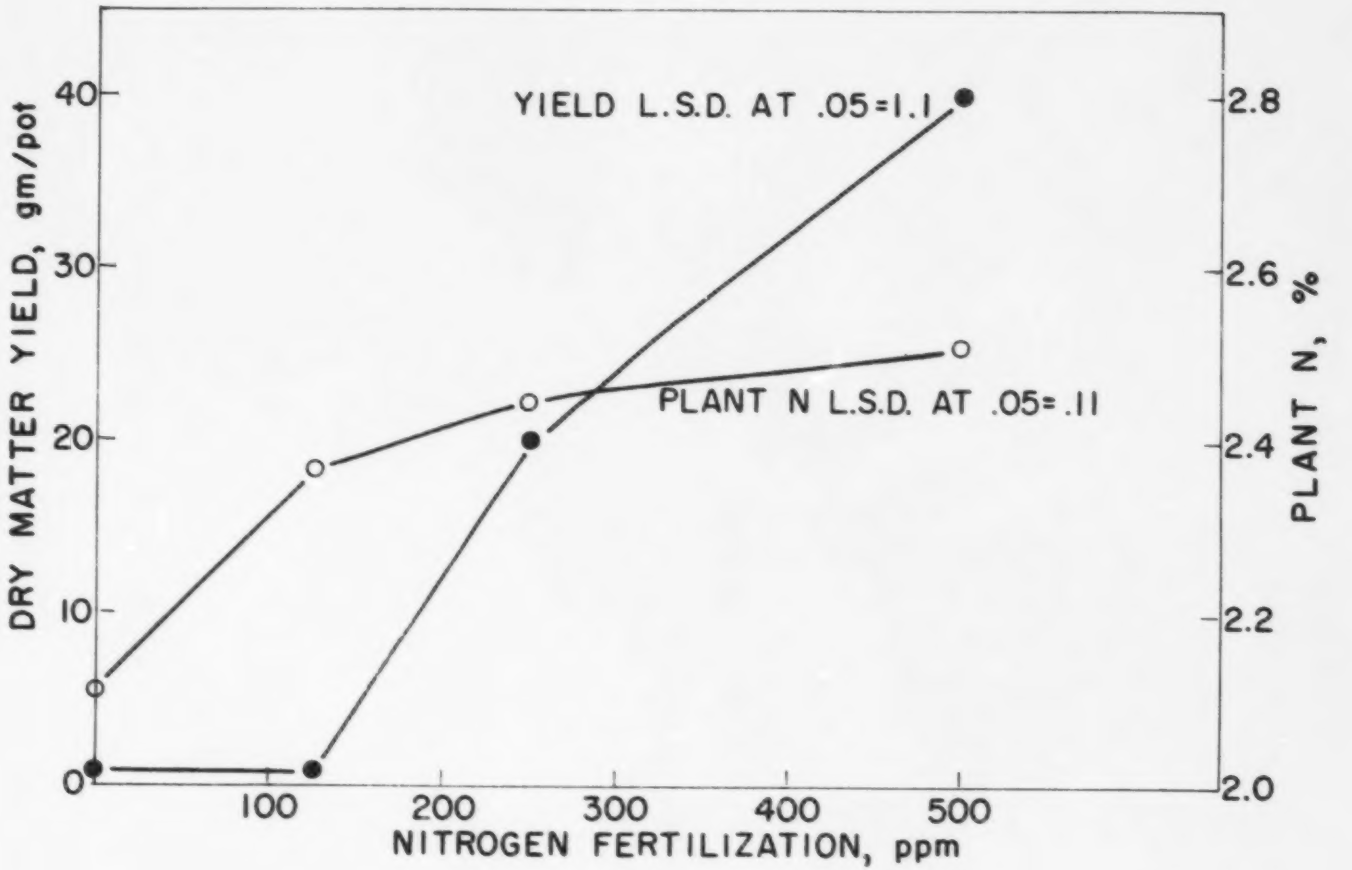

Figure 61. Influence of nitrogen fertilization on dry matter yields and nitrogen content of 42 day old corn plants. Greenhouse Exp. II.

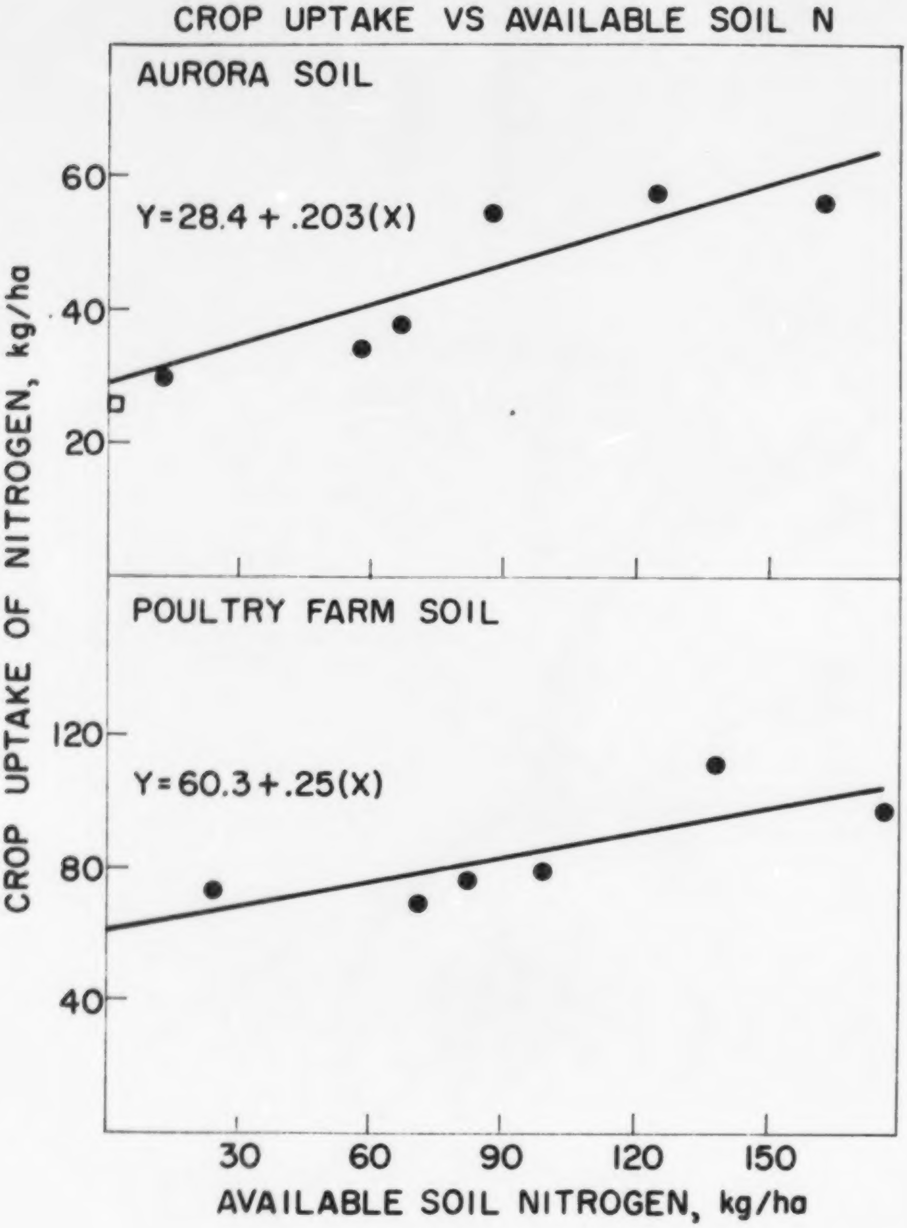

Figure 62. The relationship of nitrogen uptake by corn to nitrogen available from soil mineralization and additions of various amounts from various sources on 2 soils.

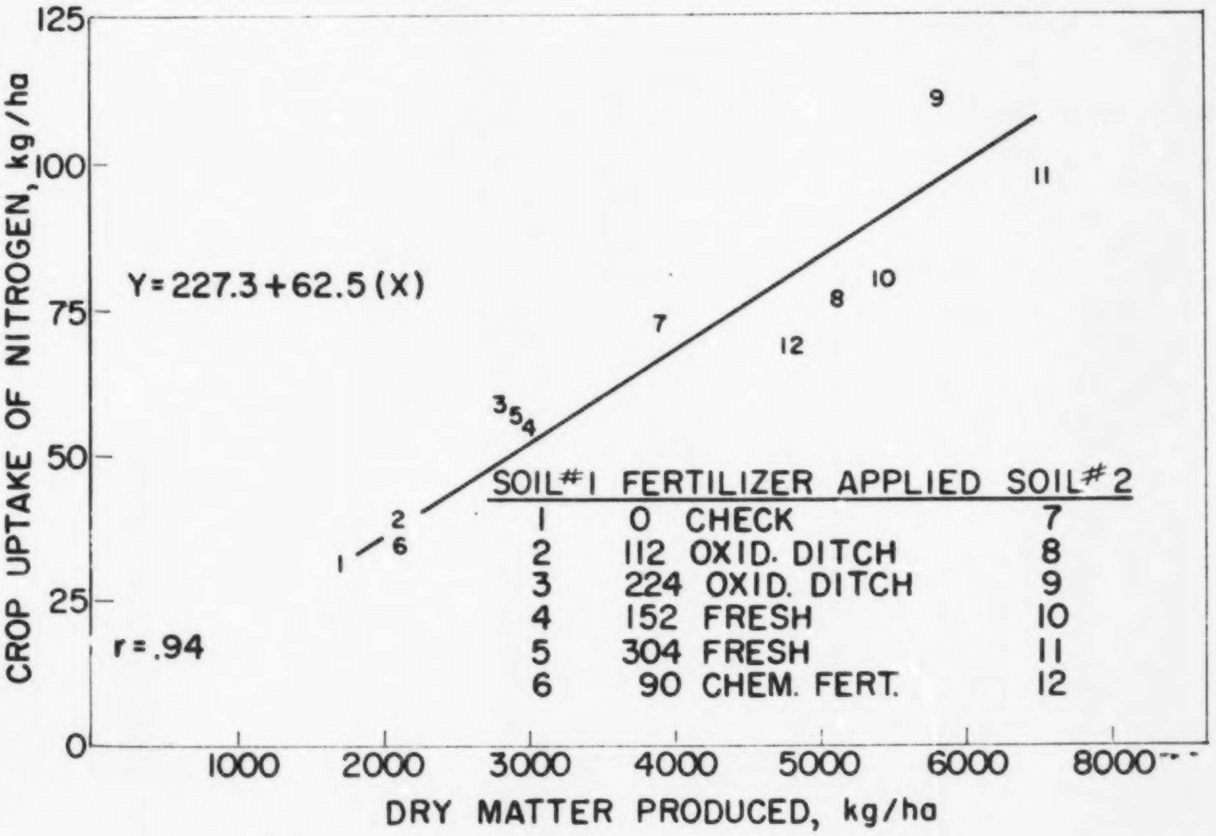

Figure 63. The relationship of nitrogen uptake by corn to dry matter produced on two soils treated with various rates of nitrogen from various sources.

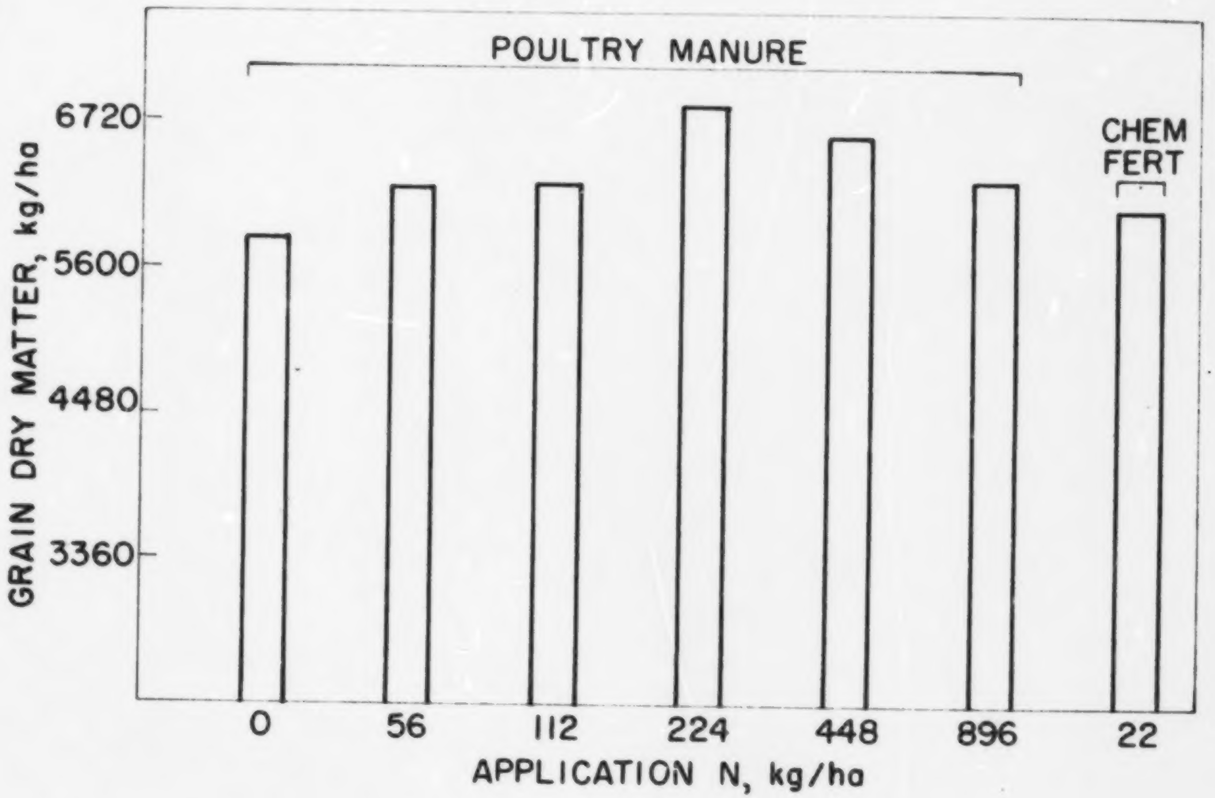

Figure 64. 1971 dry shelled corn yield from poultry waste residue study - L.S.D. between rates @ .05 = 1891

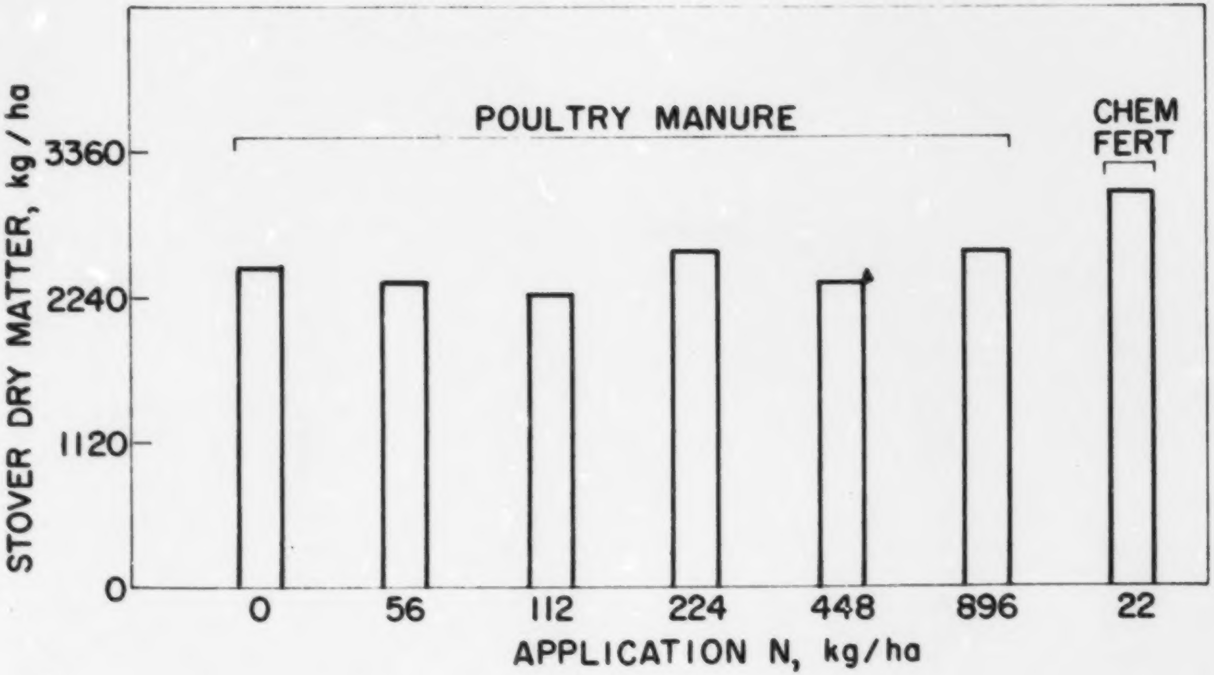

Figure 65. 1971 dry matter yields of corn stover from poultry waste residue study - L.S.D. between rates 0 .05 = 594.

Table 28. THE EFFECT OF SOIL AND NITROGEN SOURCE ON CROP UPTAKE OF NITROGEN.

	Treat No.	Source	Initial Soil N kg/ha	Fertilizer Nitrogen Added kg/ha	Assumed Nitrogen* Available kg/ha	Crop N Uptake kg/ha	End Soil N kg/ha
Soil 1	1	Check	2361	0	12	31.2	2330
	2	Oxid. Ditch	2032	112	66	38.4	2106
	3	Oxid. Ditch	1941	224	122	58.6	2106
	4	Fresh	2479	152	88	55.3	2576
	5	Fresh	2283	305	164	56.5	2531
	6	Chem. Fert.	2364	90	102	34.7	2419
Soil 2	7	Check	4665	0	23	72.8	4592
	8	Oxid. Ditch	4624	112	79	76.6	4659
	9	Oxid. Ditch	4570	224	135	111.6	4682
	10	Fresh	4810	152	100	79.3	4883
	11	Fresh	4460	305	175	97.5	4861
	12	Chem. Fert.	4500	90	113	69.2	4659

*.005 of initial soil N + 50% of manure N or 100% of commercial N.

obtained with commercial fertilizer N. All manure treatments as well as the commercial fertilizer N treatment produced somewhat higher yields than did the check or no N plot. Nitrogen uptake by grain and stover is shown in Fig. 66. Grain uptake of N was greatest at 224 kg N/ha from manure

In 1972 each increase in poultry manure rate was reflected in an increase of both grain & stover. This was true of plots treated during 1971 only, as well as plots treated both 1971 and 1972. However, yields on the plots treated both years were consistently though not significantly higher than those receiving only one years treatment. See Fig. 67 and 68.

The yield range in 1972 was from 3204 - 3944 kg/ha shelled grain on plots receiving only one year of application and from 3322-5288 kg/ha on plots receiving 2 years of the treatment. It should be noted that the highest yields in 1972 were less than the lowest yield in 1971. The yield from the 22 kg N/ha in chemical fertilizer was about equal to 50-100 lbs of N from chicken manure. Nitrogen uptake in the grain and stover was not greatly affected by treatment in 1971. In 1972, however, increased rates of N from poultry manure generally resulted in increased N uptake by both grain and stover. See Fig. 69.

Responses were obtained up to the maximum rate of N application in 1972, but not in 1971. It would appear that this was because of the very wet spring and early summer of 1972 which leached much of the nitrogen from the soil and depressed mineralization. Thus the high rates in 1972 were not in excess as they appeared to be under 1971 growing conditions. It is interesting to note that the highest N uptake in 1971 compares favorably with the highest values in 1972. See Fig. 69.

Field Runoff Studies

Data for ammonium and nitrate nitrogen taken from soil samples collected at intervals in the field indicated that there was a greater accumulation of nitrates in the subsoil (30-60 cm) where fresh manure had been applied at the highest rate when compared with oxidation ditch manure. See Fig. 70. There was very little change in subsoil nitrate content under oxidation ditch treatments when compared with the check or zero manure application. Nitrate content of surface soils also increased with time and rate to a greater extent under the fresh manure treatments compared with oxidation ditch treatments.

Movement of ammonium nitrogen from the surface soil to the subsoil was greatest at the 224 kg/ha application rate of oxidation ditch

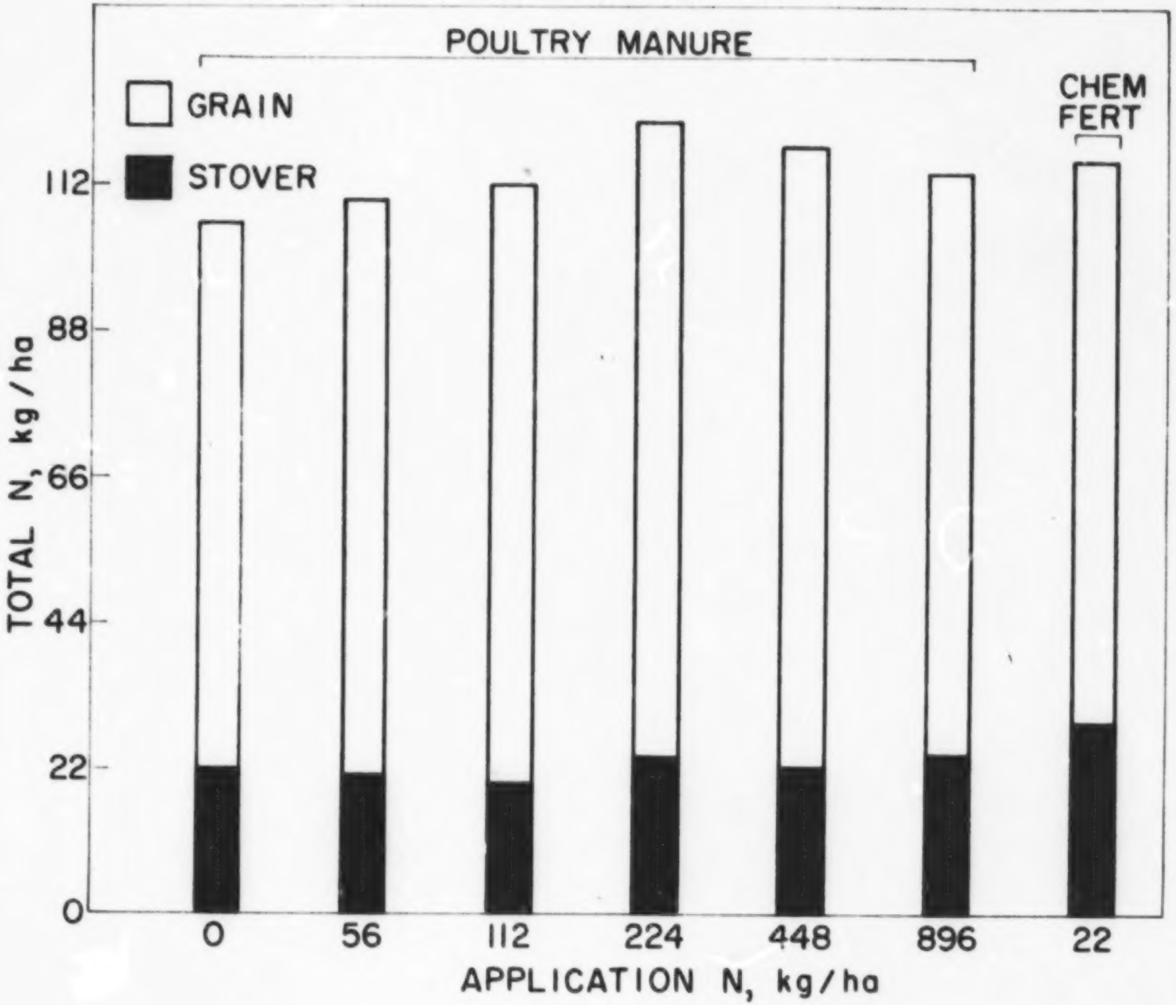

Figure 66. Total N in grain and stover 1971 from poultry waste residue study.

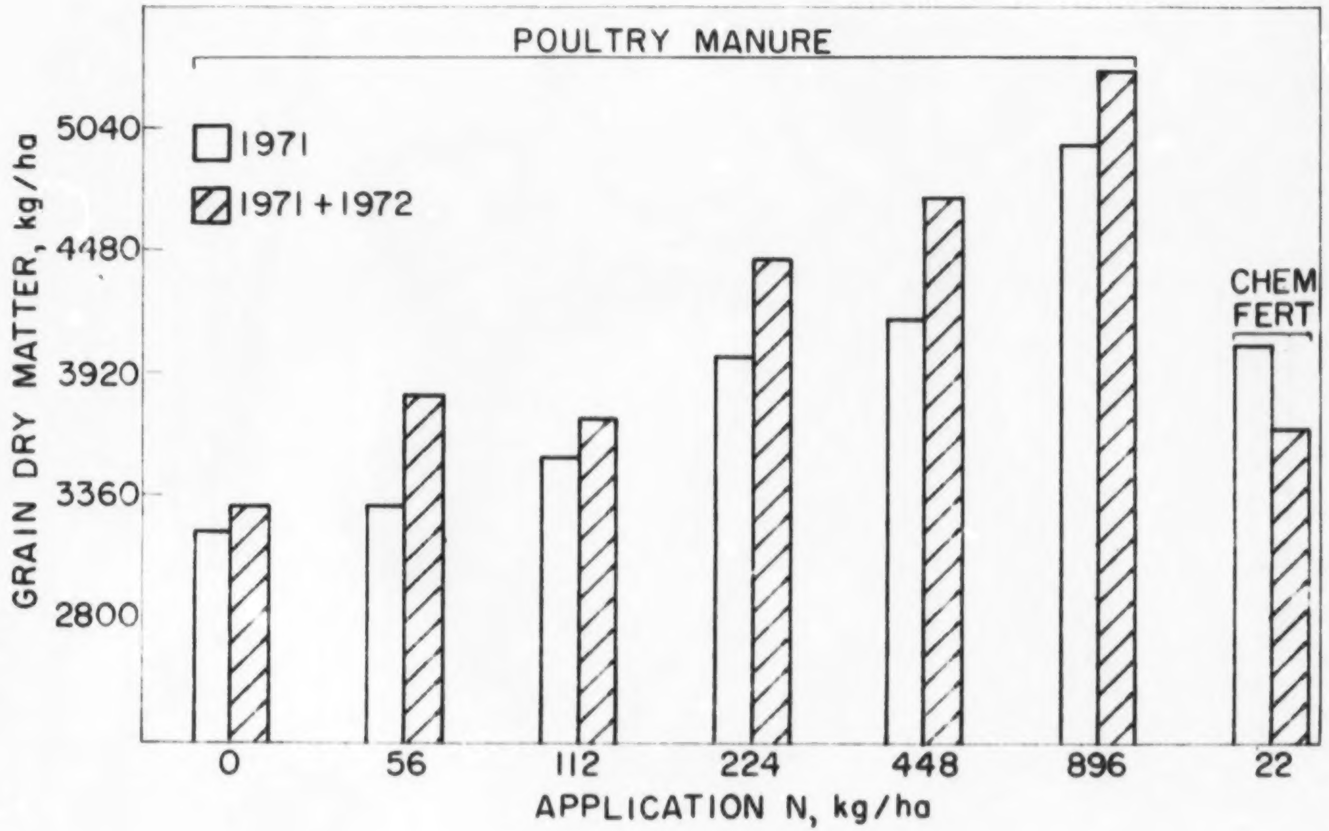

Figure 67. 1972 dry shelled corn yield from poultry waste residue study - L.S.D. between rates @ .05 = 459.

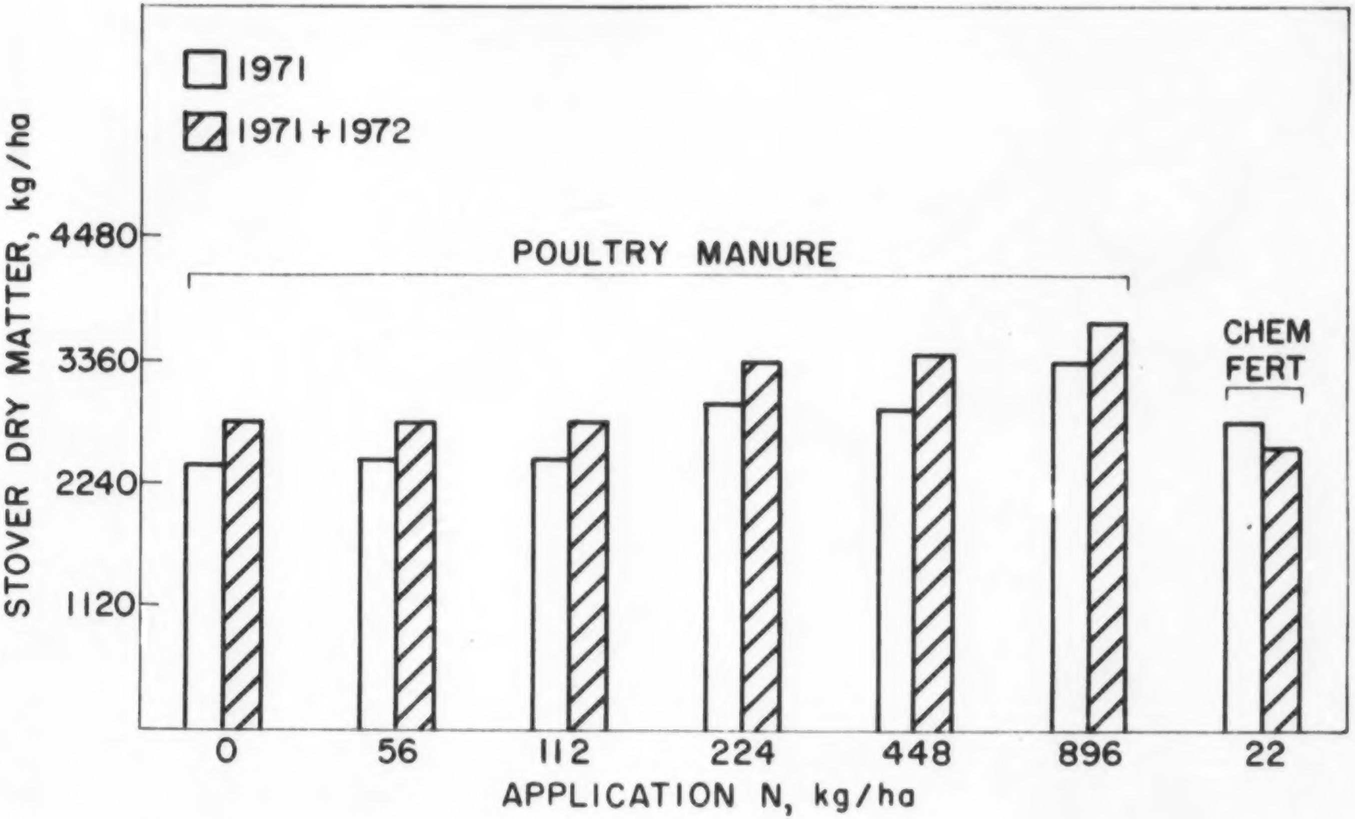

Figure 68. 1972 dry matter yields of corn stover from poultry waste residue study - L.S.D. between rates @ .05 = 318.

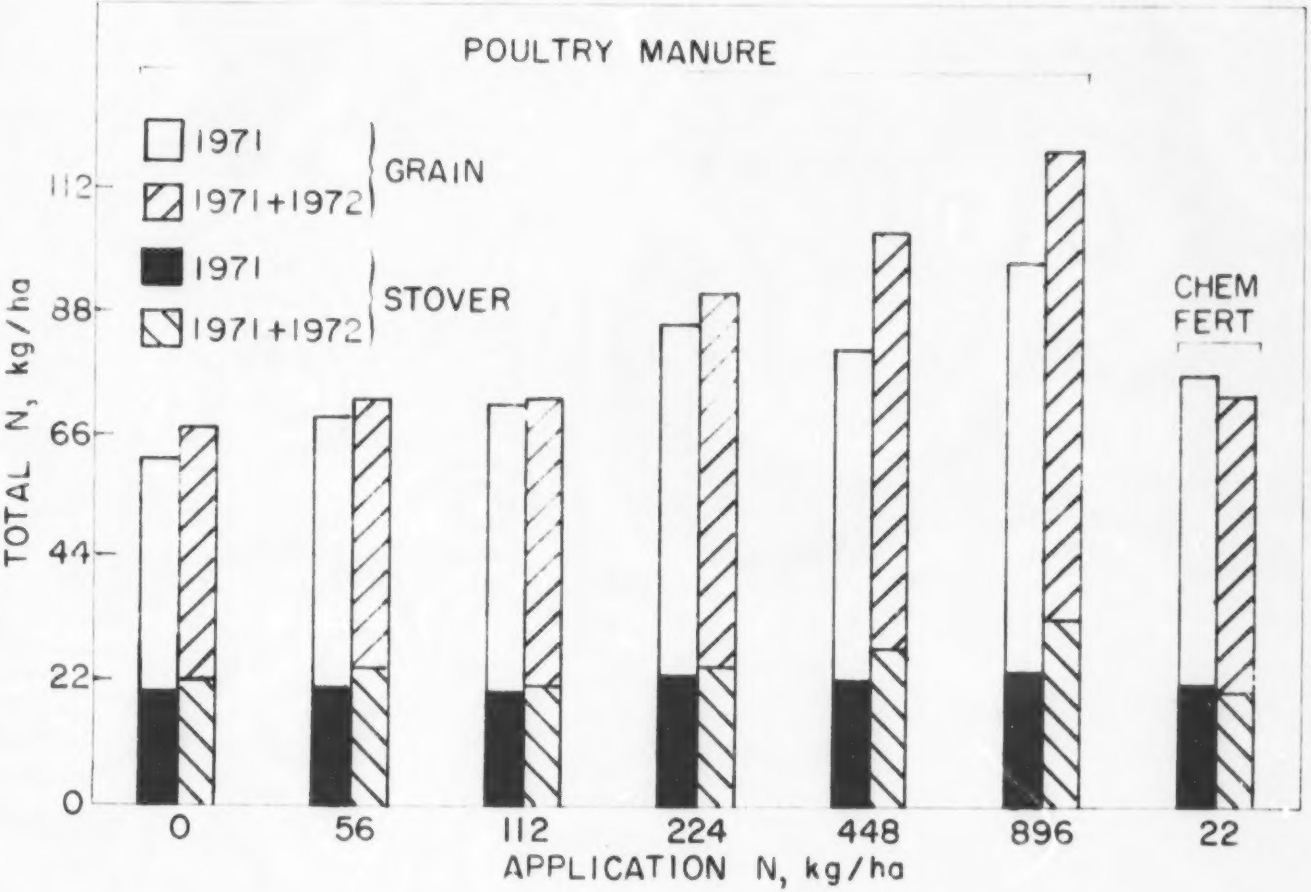

Figure 69. Total nitrogen in grain and stover from 1972 waste residue study - L.S.D. @ .05 = grain 7.3, stover 13.4, grain and stover 9.5.

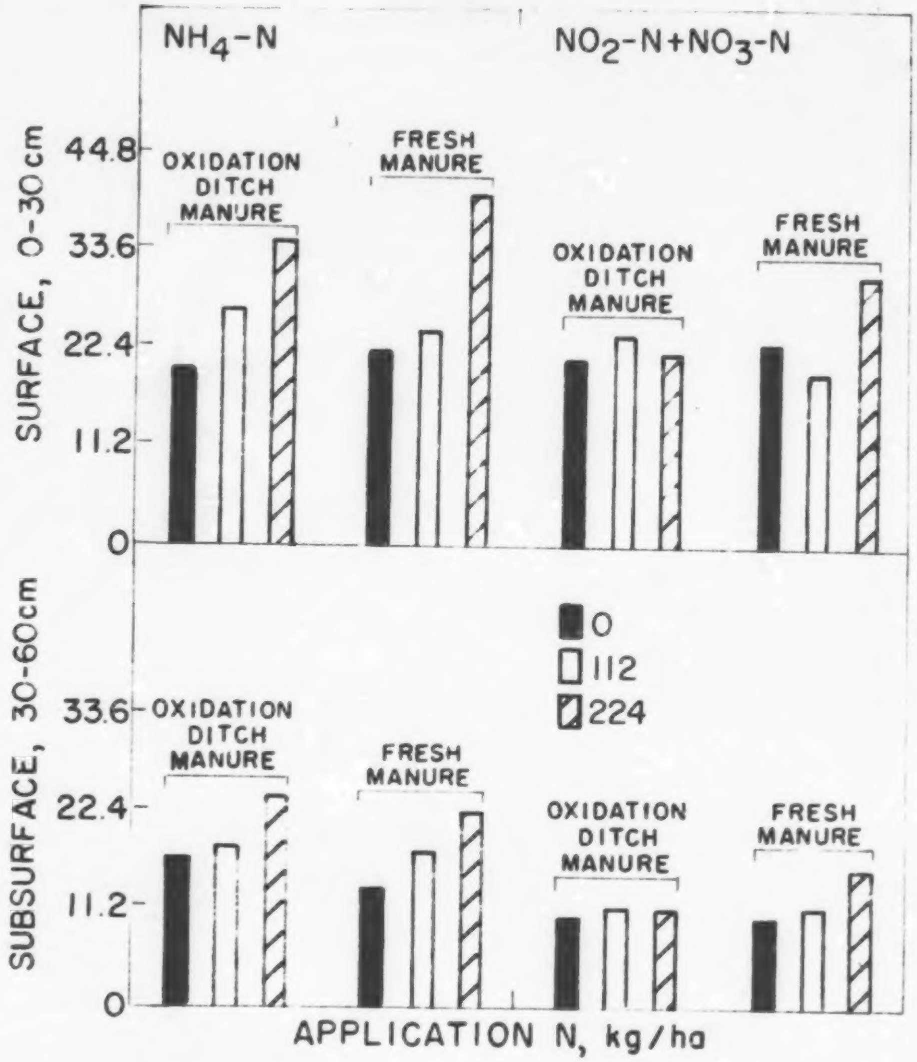

Figure 70. Surface and subsurface soil analysis. Composite of weekly samples May 25 - Aug. 3, 1972.

manure. Both the 112 and 224 kg/ha rates of fresh manure showed an increase in subsoil NH_4-N. At the 224 kg N/ha rate, there was a greater accumulation of subsoil nitrates from the fresh manure source than from oxidation ditch manure. See Fig. 70.

Due to problems associated with new installations and with flooding which accompanied hurricane Agnes, it was decided that data enterpretation would best be based on 6 selected storms for which reasonably uniform samples were collected on all plots. These storms comprise 2 prior to Agnes (June 4 and 16) for a total of 2.46 inches of rainfall and 4 storms after Agnes (July 16, 25, August 4 and 7) which total 2.03 inches for an overall total of 4.49 inches which is nearly 1/4 of the growing season rainfall.

Results from the selected storms are presented graphically in Figs. 71-78. Again, losses in surface runoff water were greatest from the check and low manure application rates. See Fig. 71. In Fig. 72, it can be seen that the lowest soluble phosphorus and NO_3-N losses occurred at the high rates of application of both manure sources. Losses of NH_4-N were greatest at the low application rate of fresh manure. See Fig. 74.

The greatest losses, particularly the sediment and its related nutrients, were associated with fresh manure at the lowest rate of application. These differences were not statistically significant at the 5% level. It is possible that oxidation ditch manure and the high rate of fresh manure provided greater bonding of soil particles thus reducing movement of soil particulate matter.

Field Study of Grass Response to Applications of Poultry Manure

Orchard Grass --

Fertilizer and manure applications were made in the Fall (Nov. 3) and Spring (May 3). A dry matter yield response was obtained with all rates (56, 112 and 224 kg/ha) of both sources, oxidation ditch and fresh manure, applied either in the fall or spring. Each of the first two harvests produced a dry matter yield increase with the exception of spring applied commercial fertilizer which resulted in a yield loss. The first cutting responded most to the fall applications and the 2nd cutting responded most to the spring application. The greatest response to fresh manure was obtained when applied in the fall, however, 224 kg/ha was superior to 112 kg/ha when applied in the spring. This could be due to a time factor allowing nitrogen to be mineralized in the soil. See Fig. 79.

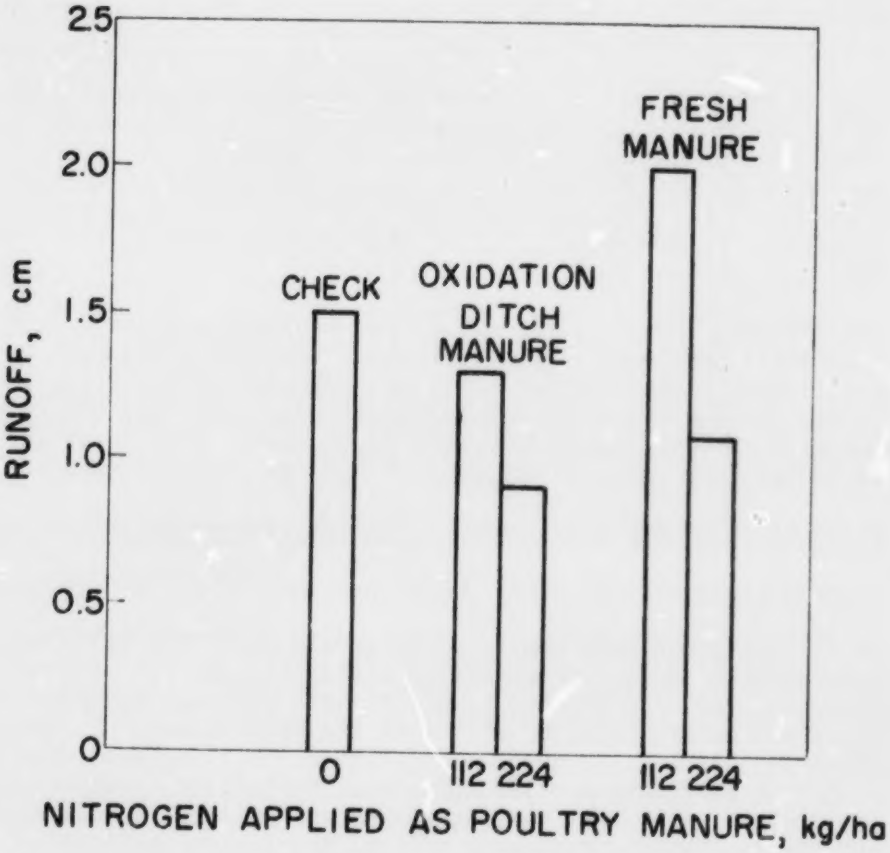

Figure 71. Cumulative surface runoff from 6 selected storms as influenced by rate and type of poultry manure. [Corrected 10% for each 1% slope difference (57)].

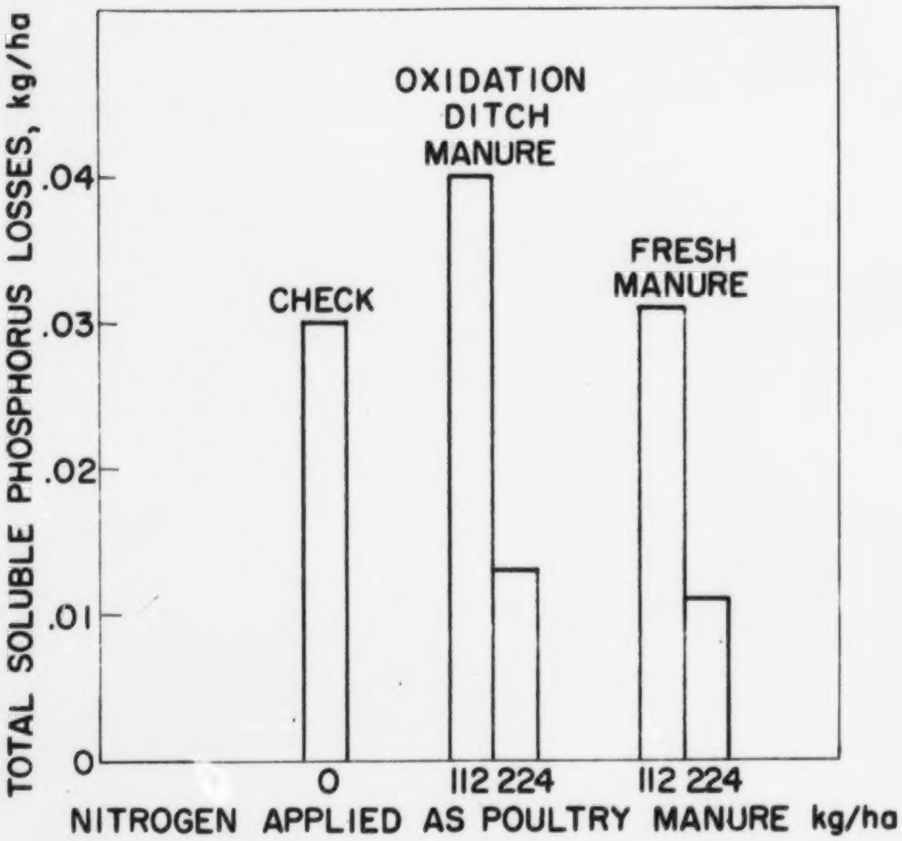

Figure 72. Cumulative soluble phosphorous losses in runoff from 6 selected storms as influenced by rate and type of poultry manure [corrected 10% for each 1% slope difference (57)].

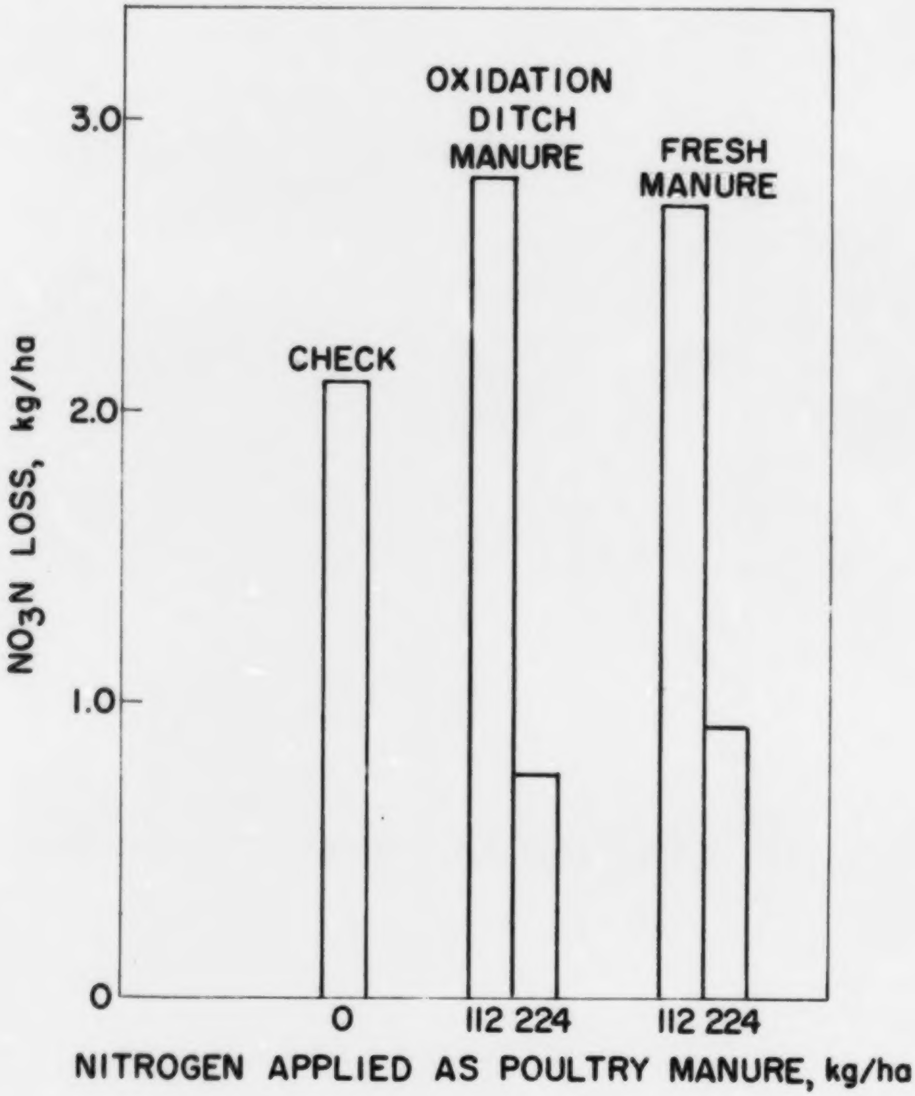

Figure 73. Cumulative NO_3-N losses in runoff from 6 selected storms as influenced by rate and type of poultry manure [corrected 10% for each 1% slope difference (57)].

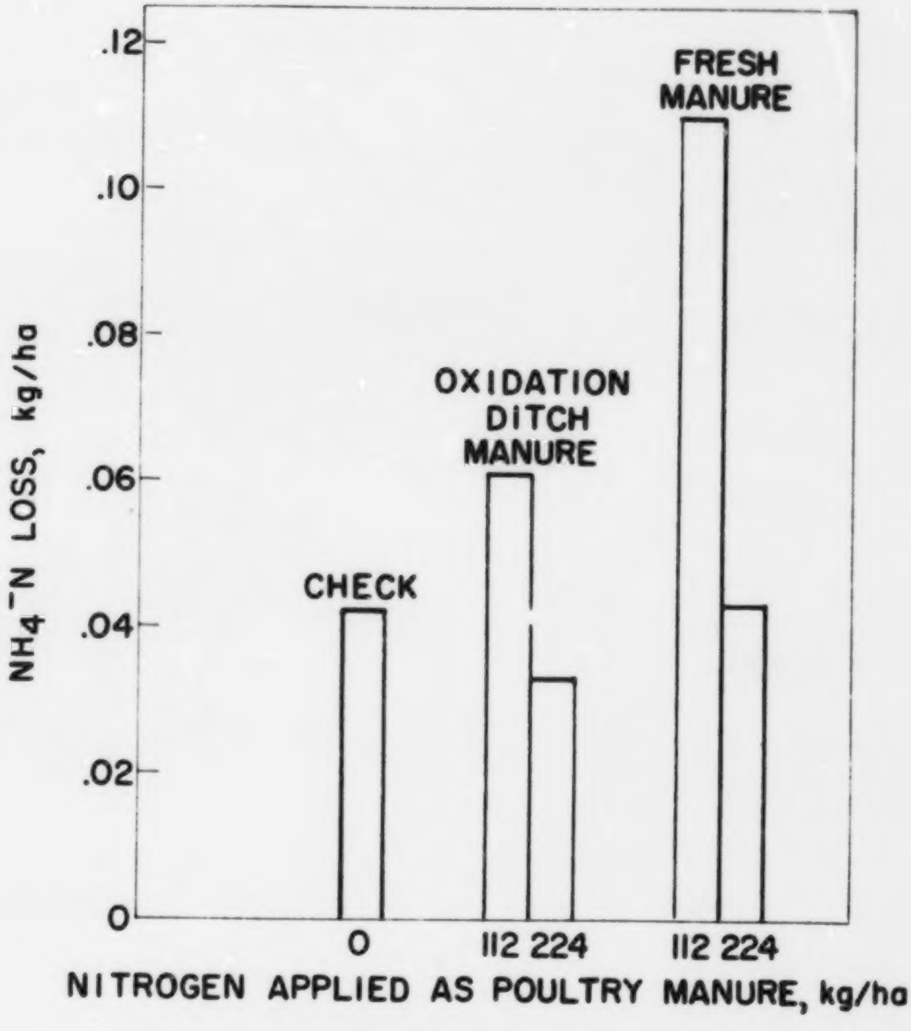

Figure 74. Cumulative NH_4-N losses in runoff from 6 selected storms as influenced by rate and type of poultry manure [corrected 10% for each 1% slope difference (57)].

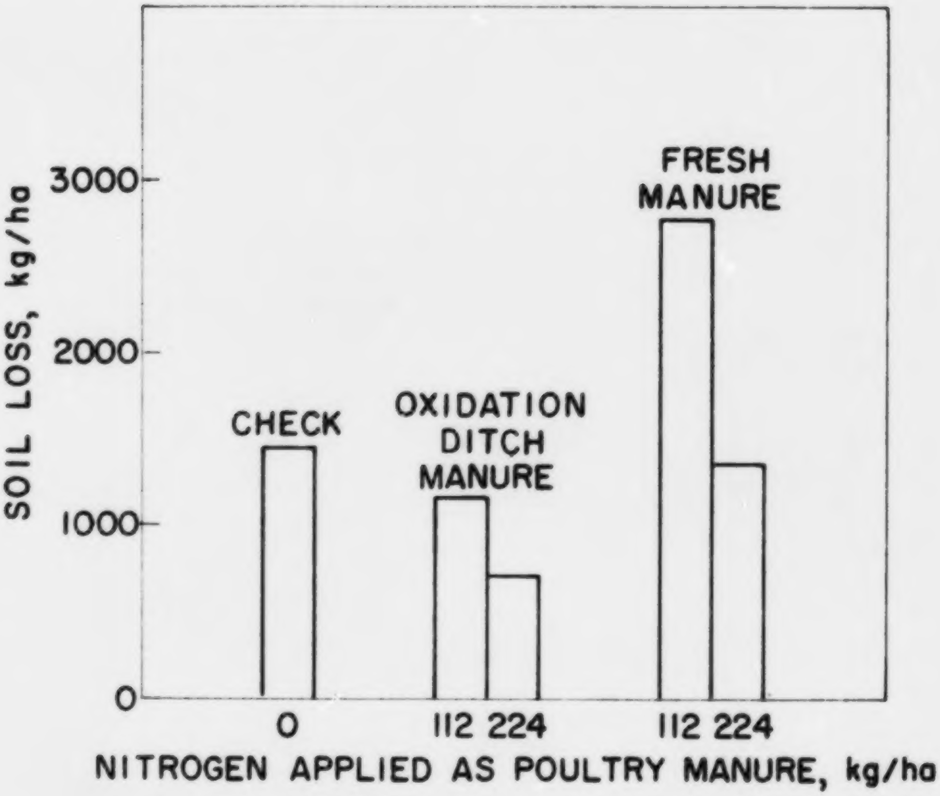

Figure 75. Cumulative Soil loss from 6 selected storms as influenced by rate and type of poultry manure [corrected for slope differences by LS ratio (52)].

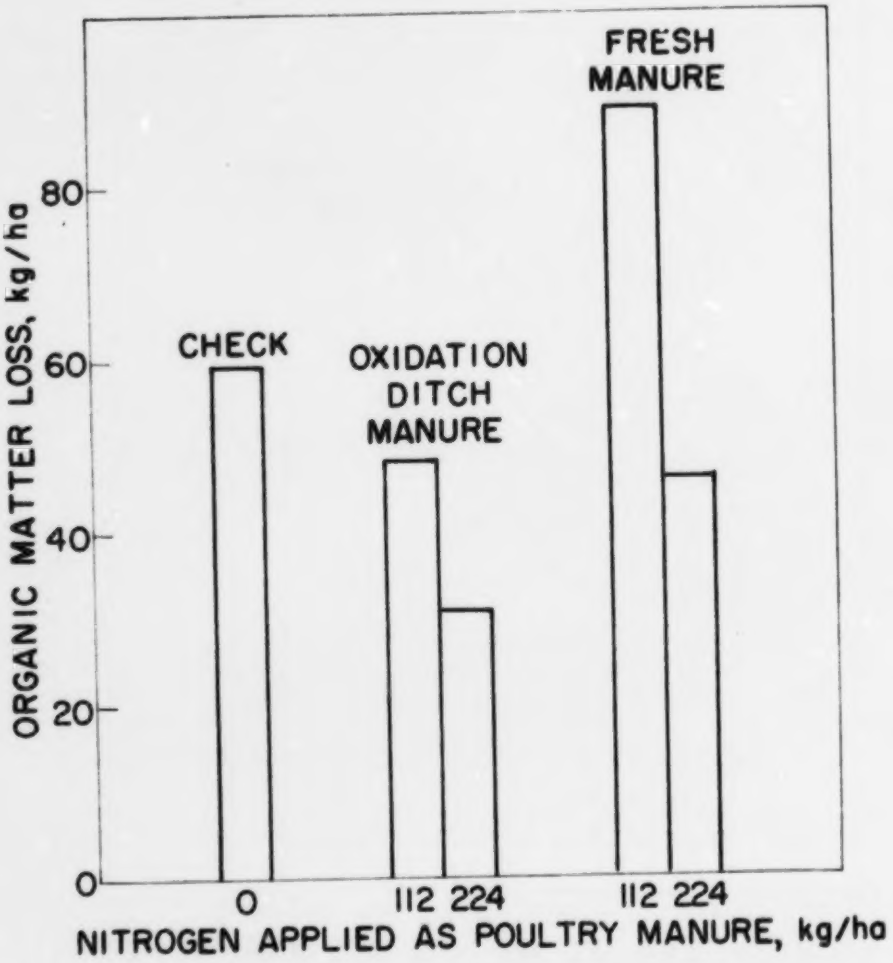

Figure 76. Cumulative organic matter loss in sediment from 6 selected storms as influenced by rate and type of poultry manure [corrected for slope differences by LS ratio (52)].

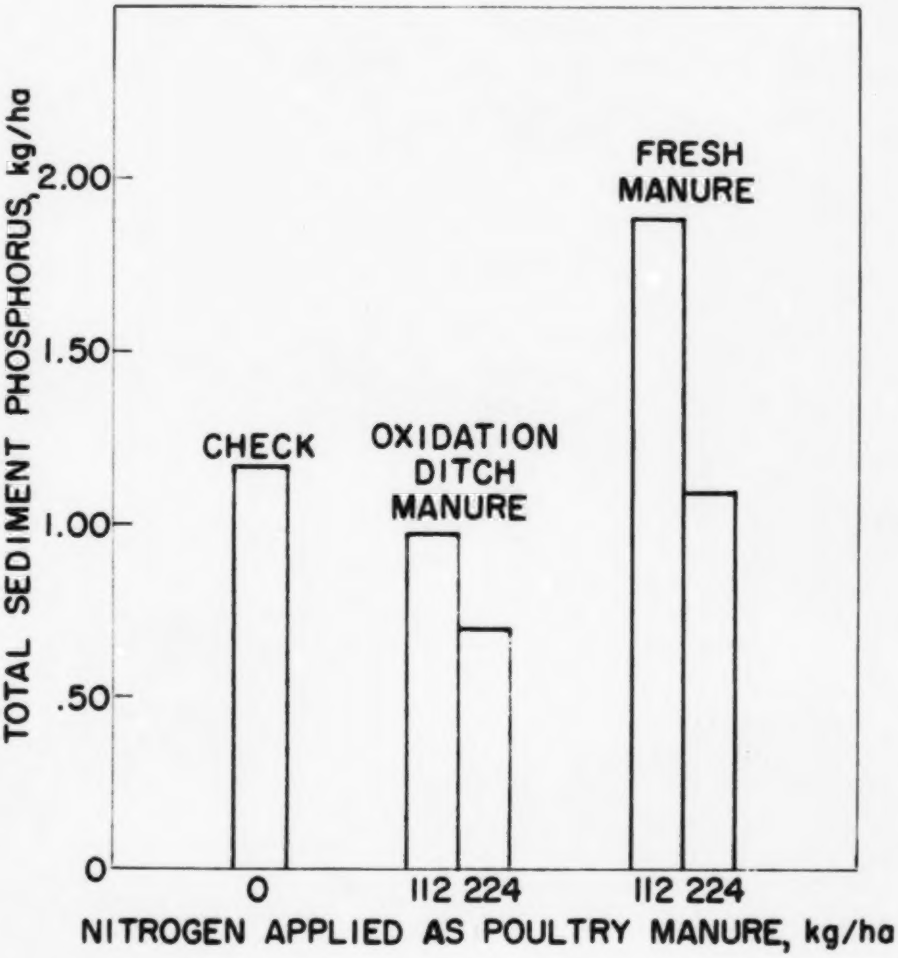

Figure 77. Cumulative total phos. loss in sediment from 6 selected storms as influenced by rate and type of poultry manure [corrected for slope differences by LS ratio (52)].

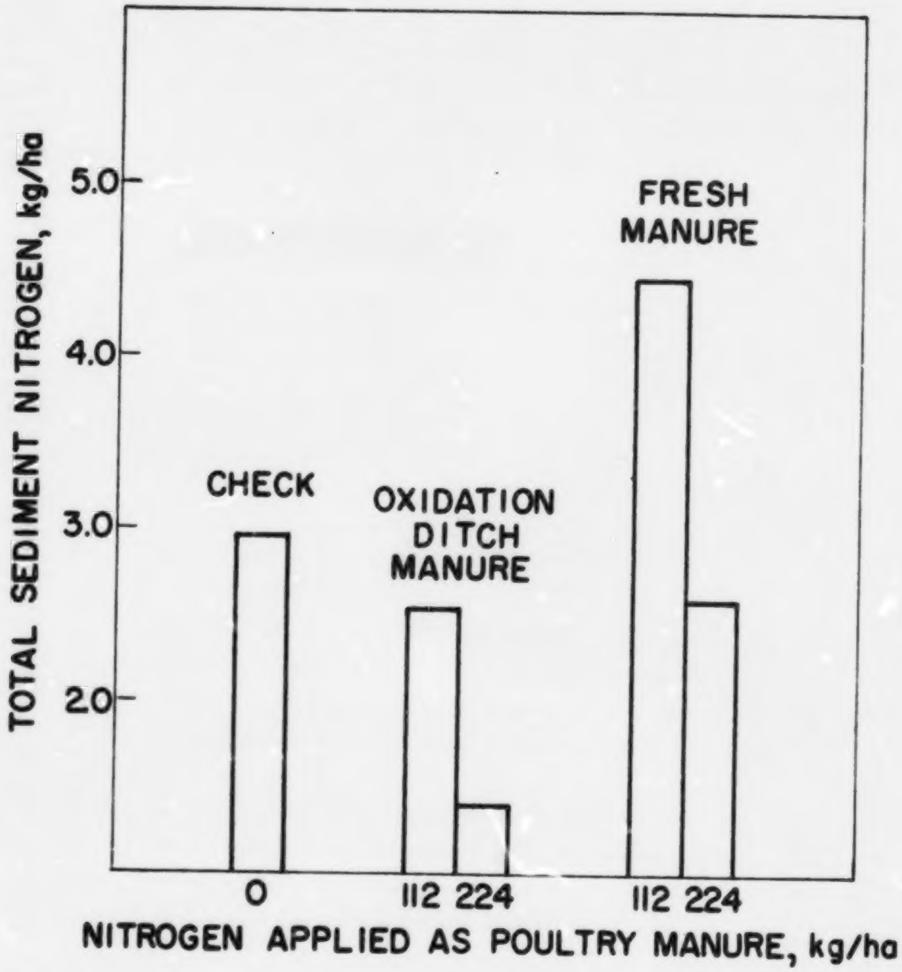

Figure 78. Cumulative total nitrogen loss in sediment from 6 selected storms as influenced by rate and type of poultry manure [corrected for slope differences by LS ratio (52)].

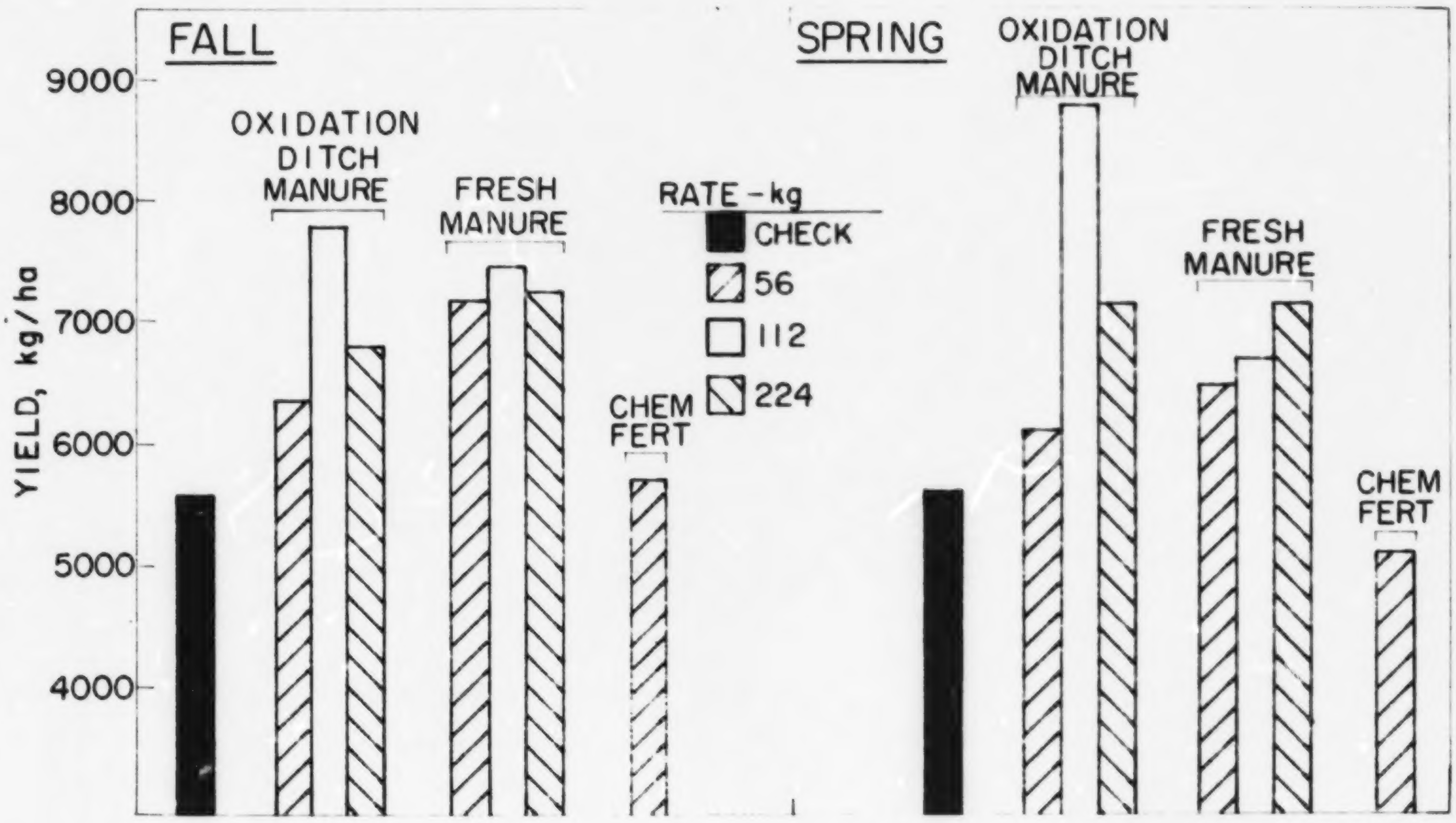

Figure 79. A comparison of the effects of 2 forms, 3 rates, and 2 times of application of poultry waste and commercial fertilizer on the yield of orchard grass (1st & 2nd cutting 1973) L.S.D. between rates @ .05 = 1225.

Brome Grass --

There were no significant yield responses to either source at any rate at any time of application when compared with the zero treatment.

There was a slight response, however, to the two highest rates of oxidation ditch material when applied in the fall and the highest rate when applied in the spring. The upper rate of fresh manure produced a slight response when applied in the fall, but none when applied in the spring. There was little or no response to chemical fertilizer at either time of application, Fig. 80.

These materials had to be surface applied without benefit of soil incorporation. The oxidation ditch material, being more liquid, penetrated into the root zone more easily than the fresh manure which was more viscous. Spring application of the fresh manure resulted in a substantial amount of the young foliage being covered for a time with manure. There were no visual symptoms of foliage "burning". The time of application, however, was sufficiently late that soil water movement downward would tend to limit the movement of nutrients into the deeper root zone. It should also be noted that this experiment had only two replications so that the information here presented only serves as a guide for further study.

Sullivan Co. Study

The composition of the manure used in this experiment is presented in Table 29 along with the actual amounts of N, P and K added per ton of fresh manure. The response of corn to varying rates of this manure is given in Table 30. Each observation as illustrated in the upper portion of the table is comprised of two replicates. The mean for each factor is given in the lower segment of the table. It is evident from the data in Table 30 that the addition of cow manure the previous year had only a small and insignificant influence on increasing corn yields when making a comparison over all rates of poultry manure.

The yield of both grain and silage did not show a significant response to poultry manure as compared to the check plot for rates not exceeding 200 tons/ha. Apparently the addition of a starter fertilizer of 7-7-7 kg of N - P_2O_5 - K_2O in itself and the availability of these elements from the soil by the mechanism of mineralization was sufficient to produce respectable yields. A significant negative response is evident for rates exceeding 200 tons/ha (90 tons/acre).

The effects of rate of manure application on plant population and yield are illustrated in Fig. 81. Inorganic N levels in the topsoil and subsoil are illustrated in Fig. 82.

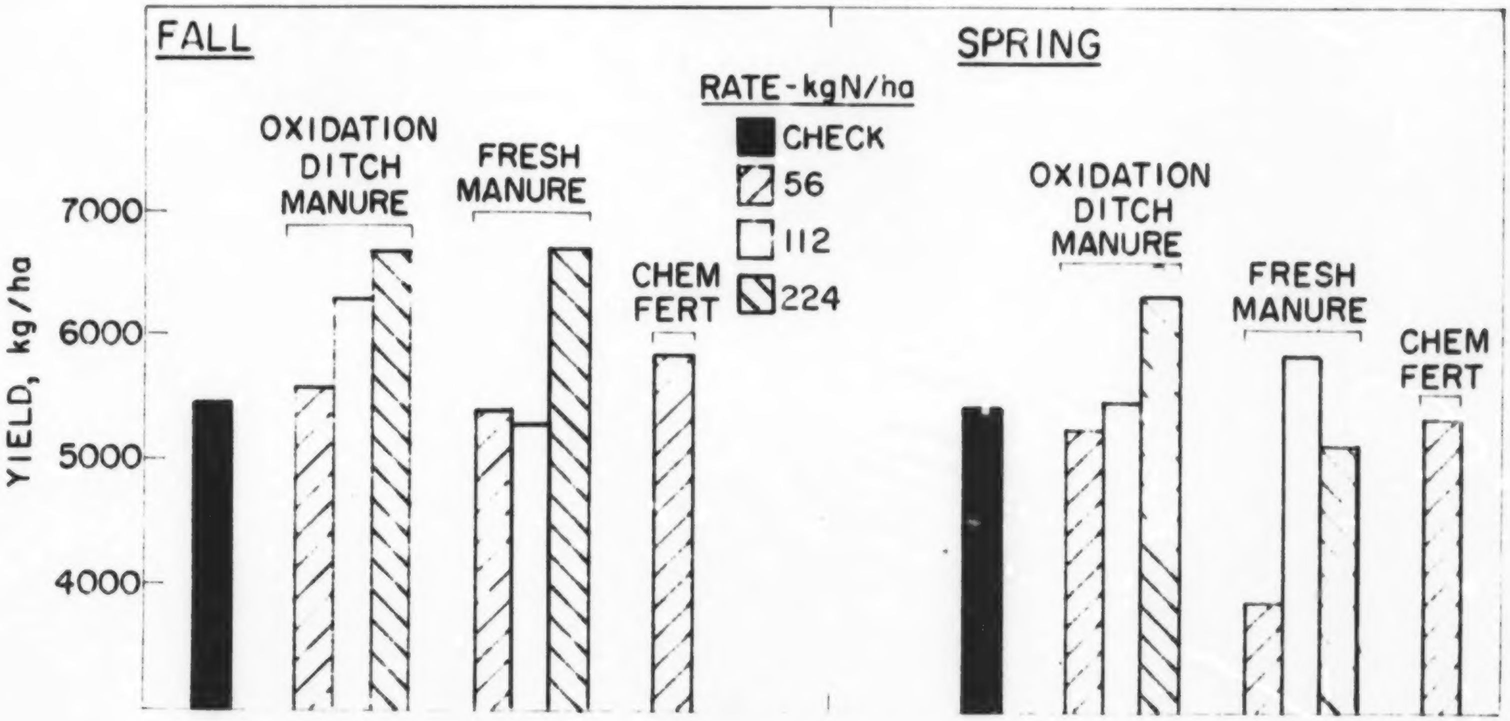

Figure 80. A comparison of the effect of 2 forms, 3 rates and 2 times of application of poultry waste and commercial fertilizer on the yield of bromegrass (1st and 2nd harvest 1973) L.S.D. between rates @ .05 = 1939.

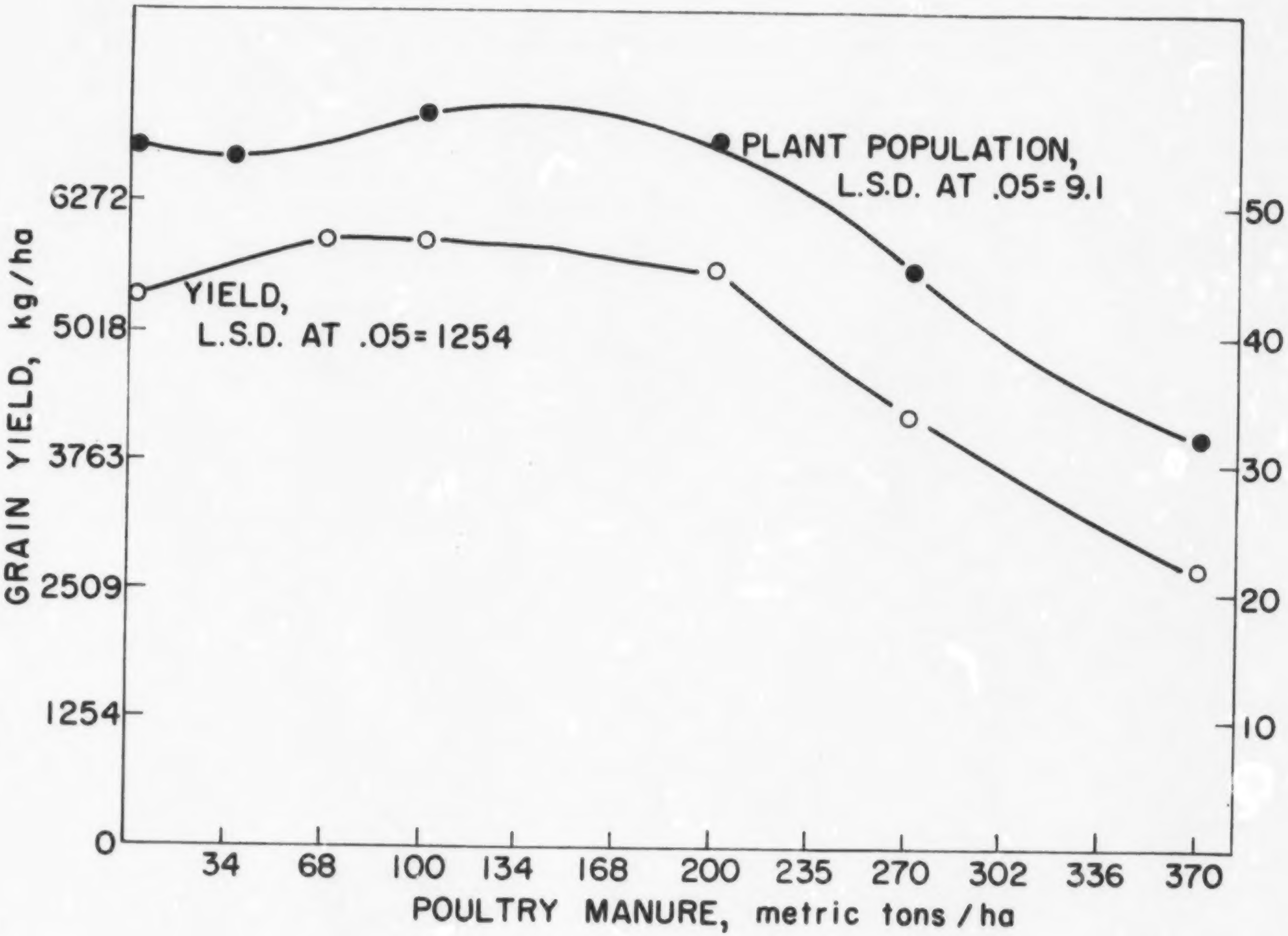

Figure 81. A comparison of corn grain yield and plant population as influenced by additions of poultry manure.

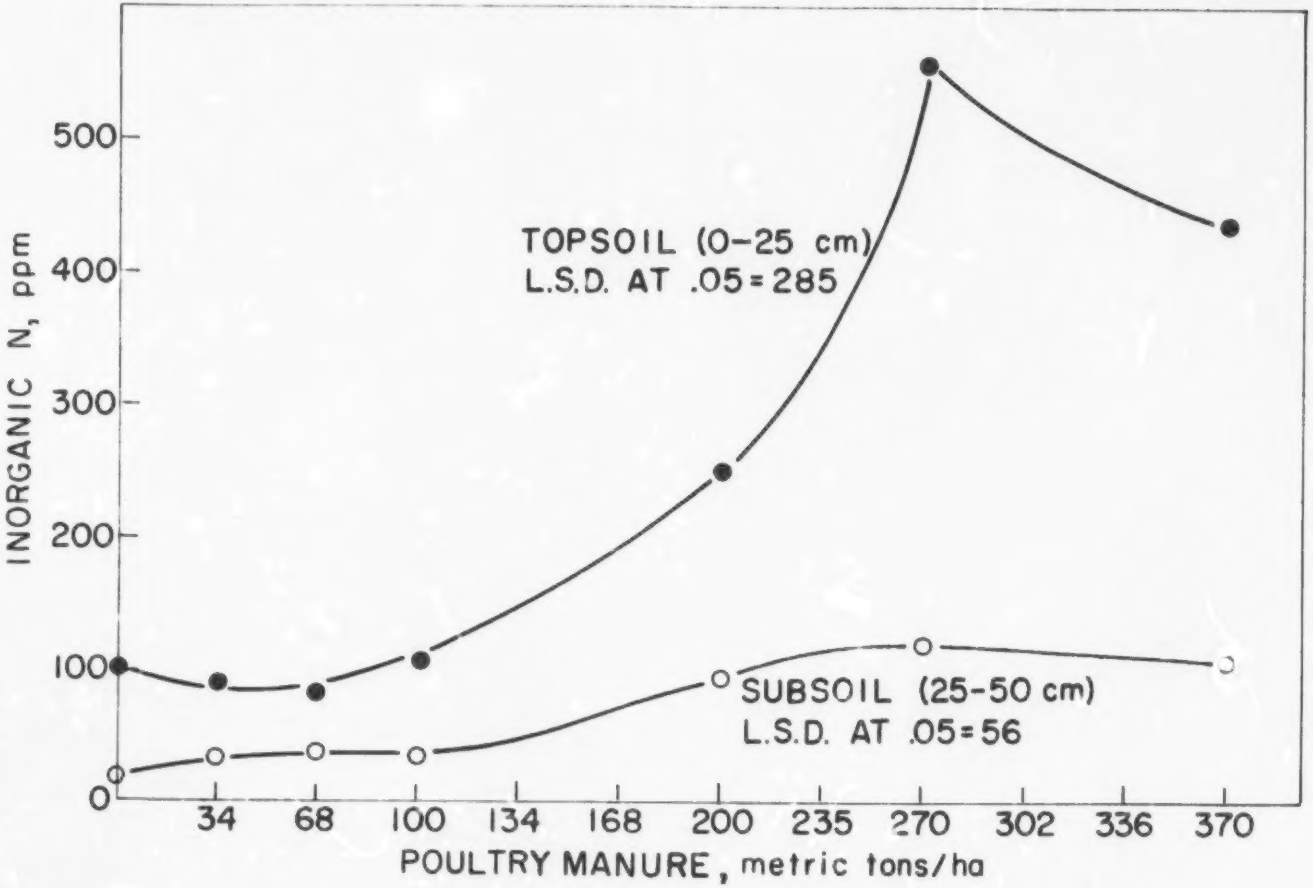

Figure 82. Inorganic -N concentrations in soil as influenced by rate of poultry manure additions. Sampled 7/15/73.

Table 29. COMPOSITION OF PULLET MANURE ON A DRY WEIGHT BASIS

	H_2O	Total N	NH_4-N	P	K	$CaCO_3$ Equiv.	Soluble Salts NaCl Equiv.	pH
%	52	4.77	1.27	0.85	1.92	6.2	3.25	6.7
kg/dry metric ton		47.7	12.7	8.5	19.2	62.0	32.5	
lbs/dry ton		95.4	25.4	16.9	38.4	124.0	65.0	

Table 30. CORN YIELD DATA AS INFLUENCED BY 1973 POULTRY MANURE ADDITIONS.

Rate, kg/ha	Cow Manure (72) Addition, 22 t/ha	Grain, kg/ha @15%	Silage, t/ha @75%	Population Plants/ha x 10^3
0	Yes	5770	38.1	55.1
	No	4892	33.8	52.6
34	Yes	6021	38.3	51.9
	No	5017	33.2	53.4
68	Yes	6335	43.5	56.1
	No	5393	36.1	55.6
100	Yes	5833	36.1	54.3
	No	5896	36.3	58.5
200	Yes	5457	32.0	52.1
	No	5896	37.6	57.1
270	Yes	3889	25.5	42.0
	No	4515	26.7	47.4
370	Yes	2634	17.2	24.9
	No	2885	18.8	38.5
		MEANS		
Cow Manure[a]	Yes	5134	33.0	48.0
	No	4928	31.8	51.9
Rate, kg/ha	0	5331	36.0	53.9
	34	5519	35.8	52.7
	68	5864	39.8	55.9
	100	5865	36.1	56.4
	200	5677	34.7	54.6
	270	4242	26.1	44.7
	370	2760	18.0	31.7
L.S.D@5% For Rate		1254	7.2	9.1

---

[a] Non-significant difference @ 5% level.

The fertility status of the soil before poultry manure was applied is presented in Tables 31 and 32. It is evident that the prior soil fertility status for each treatment area was essentially identical, since there were no significant differences in the amounts of organic matter, N, P, and K present. Any fluctuation in yield between treatments should unquestionably be a function of the rate of the poultry manure applied.

The yield of corn appears to be closely related to the stand count. See Fig. 81. Both yield and stand count decrease with additions exceeding 200 tons/ha (90 ton/acre). It would seem logical that the yield would increase with increasing increments of poultry manure because of the addition of increasing rates of the primary plant nutrients, especially nitrogen. See Fig. 82. In view of this, it is interesting to note that there is a negative relationship between available nitrogen (inorganic N), yield and plant population. Apparently, either a toxic level of a certain form of nitrogen is coming into play at the higher rates and/or salt concentration is having an adverse effect.

SUMMARY

A series of greenhouse studies were made using three representative soils. In one of these soils the pH was adjusted to range from 4.1 to 7.2. A series of studies on poultry manure rate applications were made on the various soils and at the various pH levels. The attempt was to determine the best possible rate of applying treated and untreated poultry manure. Acid soil conditions resulted in the nitrogen in the poultry manure being held much more firmly against the forces of leaching and nitrification as compared to neutral pH values for the soil.

Greenhouse corn growth and dry matter increased in accordance with rates of nitrogen fertilizer applied in the poultry manure. For certain treatments of oxidation ditch treated manure and raw manure at pH 7.2, NO_2^- ions accumulated in the soil and became toxic to the corn plants. In general there was limited variation in dry matter corn yields produced by the various treated manures. At higher rates of application raw manure was a poorer source of nitrogen than were treated manures.

Field studies were conducted on the residual benefits of poultry manure applied to corn as a fertilizer. These tests were made by applying poultry manure to corn plots at varying rates during the year 1971.

Table 31. SOIL ANALYSIS OF TOPSOIL (0-25 cm) TAKEN PRIOR TO POULTRY MANURE ADDITIONS AND CORN PLANTING.

Rate, t/ha	Cow Manure (72) Addition, 22 kg/ha	O.M., %	P, ppm	K, ppm	Total-N, ppm	Soluble Salt NaCl Equiv. %
0	Yes	4.5	11	153	1963	.009
	No	4.3	7	138	1937	.011
34	Yes	4.5	10	142	1913	.012
	No	4.5	9	141	2045	.026
68	Yes	4.4	15	143	1900	.009
	No	4.5	13	142	2035	.015
100	Yes	4.9	15	159	2050	.013
	No	4.4	9	149	1850	.007
200	Yes	4.4	9	149	2000	.011
	No	4.9	12	171	2250	.015
270	Yes	5.0	17	199	2250	.020
	No	4.5	12	165	2065	.016
370	Yes	4.4	12	151	1900	.011
	No	4.2	9	149	1850	.013

MEANS

Cow Manure[a]	Yes	4.6	13	157	1997	.012
	No	4.5	10	151	2005	.015
Rate,[a] t/ha	0	4.4	9	146	1950	.010
	34	4.5	10	142	1979	.019
	68	4.5	14	143	1968	.012
	100	4.7	12	154	1950	.010
	200	4.7	11	160	2125	.013
	270	4.8	15	182	2158	.018
	370	4.3	11	150	1875	.012

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[a] Non-significant @ 5% level.

Table 32. SOIL ANALYSIS OF SUBSOIL (25-50 cm) TAKEN PRIOR TO POULTRY ADDITION AND CORN PLANTING.

Rate, t/ha	Cow Manure (72) Addition, 22 kg/ha	O.M., %	P, ppm	K, ppm	Total-N, ppm	Soluble Salt NaCl Equiv. %
0	Yes	2.0	2.5	76	987	.0035
	No	1.2	1.0	61	950	.0030
34	Yes	1.4	2.0	58	763	.0020
	No	1.3	1.5	55	687	.0010
68	Yes	2.2	4.0	83	1025	.0055
	No	1.7	2.0	63	875	.0010
100	Yes	0.9	1.0	51	575	.0010
	No	0.9	1.5	63	675	.0010
200	Yes	1.5	1.5	63	700	.0030
	No	1.6	2.5	79	815	.0055
270	Yes	1.6	2.0	91	775	.0010
	No	1.7	3.5	73	875	.0030
370	Yes	1.5	2.0	69	800	.0010
	No	2.1	2.0	70	1025	.0030
MEANS						
Cow Manure[a]	Yes	1.6	2.1	70	804	.0024
	No	1.5	2.0	66	843	.0025
Rate,[a] kg/ha	0	1.6	1.8	69	969	.0033
	34	1.4	1.8	57	725	.0015
	68	2.0	3.0	73	950	.0033
	100	0.9	1.3	57	625	.0010
	200	1.6	2.0	71	758	.0043
	270	1.7	2.8	82	825	.0020
	370	1.8	2.0	70	913	.0020

[a] Non-significant @ 5% level.

Yield response varied with the season. Maximum yields were obtained with 100 lbs of nitrogen in 1971 and up to 800 lbs nitrogen in 1972. In 1972 these plots were divided so one portion could be manured and one portion could be left unmanured. A comparison of corn yields showed that the residual influence of the previous years manuring was great enough so that 80-90% of the corn yield was sustained without additional manure application. Additional information on fertilizing corn with poultry manure was obtained from a field trial in cooperation with a county agent. It was apparent from this field trial that applications of poultry manure in excess of 30 tons per hectare on corn greatly depressed corn yields. This yield depression was associated with increased salt content of the soil.

Additional soil fertility trials were made with Orchard grass and Bromegrass. Varying rates of oxidation ditch treated manure and raw poultry manure were applied both spring and fall on these two grasses. There was a statistically significant yield increase with Orchard grass for applied poultry manure. This increase was greater for fall applied manure. In the case of Bromegrass there was no yield increase for poultry manure applied spring or fall.

A series of runoff measuring plots were installed. Corn was grown on these plots. There were no significant differences in runoff values for water soluble phosphorus, nitrate, or ammonium ions. Also, there were no differences in the solid phase of these substances lost from the plots.

SECTION VII

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SECTION VIII

APPENDICES

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Table A1. SOLIDS ACCUMULATION IN A CONTINUOUSLY FILLING REACTOR WITH NO INTENTIONAL WASTAGE OF SOLIDS

The solids entering the ditch are comprised of degradable and non-degradable fractions.

If 'f' is the fraction of degradable solids then the quantity of non-degradable solids is C_i (1-f); where C_i is the total concentration of solids.

Total solids concentration = concentration of degradable solids + concentration of non-degradable solids

i.e.

$$C_i = \underbrace{[C_i.f)]}_{\text{degradable}} + \underbrace{[C_i(1-f)]}_{\text{non-degradable}}$$

As manure is added daily to the oxidation ditch, the non-degradable solids accumulate and the degradable solids fractions that are added daily are in varying stages of degradation. The concentration of total solids after the time 't' can be calculated if the rate of decomposition of degradable solids is known. It is assumed that this follows first-order reaction kinetics such that

$$S_t = S_0 . \exp(-kt)$$

where S_t and S_0 are the concentration of degradable solids at times 't' and zero. 'k' is the rate constant.

Therefore, the total solids content after 't' days of addition is:

$$C_t = \text{(quantity of inert solids)} + \text{(quantity of the degradable solids in the system)}$$

$$(C_t = C_i . f \{e^{-kt} + e^{-k(t-1)} + --- 1\} + \text{inert solids}$$

$$= \left\{ \begin{array}{l} \text{Degradable solids of 1st addition re-} \\ \text{maining after 't' days plus degradable} \\ \text{solids of 2nd addition remaining after} \\ \text{'t' days ----- plus degradable solids} \\ \text{added on the day 1} \end{array} \right\} + \text{inert soli}$$

$$= C_i . f . e^{-kt} (1+e^{k} + e^{2k} + ---- e^{tk}) + \text{inert solids}$$

This is a geometric series of the sum

$$= a \frac{(1-r^n)}{(1-r)}$$

$$= C_i f \, . \{ \frac{e^{-kt} - e^k}{1-e^k} \} + \text{inert solids}$$

$$= C_i f \, . \{ \frac{1-e^{-k\,(t+1)}}{1-e^{-k}} \} + \text{inert solids}$$

$$= C_i f \, . \{ \frac{1-e^{-k\,(t+1)}}{1-e^{-k}} \} + C_i \, (1-f) \;\; . \;\; t$$

If the rate constant is expressed to the base 10; then

$$C_t = C_i f \; . \; [\frac{1-10^{-k\,(t+1)}}{1-10^{-k}}] + C_i \, (1-f) \, t$$

Using the value of $k = 0.161^{day-1}$ as obtained in this report, and assuming $C_i = 0.855$ g/liter and assuming that 75% of this is degradable

$$C_t \text{ after 20 days} = \frac{C_i(0.75)(0.99958)}{0.3098} + 0.25 \, C_i \; .20$$

$$= 6.3298 \text{ g/liter}$$

C_t after 30 days = 8.463 g/liter

C_t after 40 days = 10.595 g/liter

Thus, in the operation of an oxidation ditch it will take 40 days to reach a 1.1% solids concentration.

Use of the above Equation for the Verification of the Total Solids Balance in the Pilot Plant Oxidation Ditch:

Total solids contributed from 227 birds

C_i = 0.6525 g/l/day

Total period of operation (t) = 276 days

Final concentration of total solids = 8.5% (85 g/l)

Assuming k = 0.161 per day, what would be the value of f? (i.e., fraction that is degradable)

Using the equation:

$$C_t = C_i \cdot f \left\{ \frac{1-10^{-k\,(t+1)}}{1-10^{-k}} \right\} + C_i\,(1-f)\,t$$

$$85 = (0.6525) \cdot f \cdot \left\{ \frac{1-10^{-.161\,(276\,+\,1)}}{1-10^{-0.161}} \right\}$$

$$+\ 0.6525 \cdot (1-f) \cdot 276$$

$$f = 0.534 \text{ or } 53.4\%$$

The observed loss in total solids was 53%(44). The predicted value is in good agreement with the observed value, suggesting that the models developed in this section can be used satisfactorily for the production of solids accumulation in a continuously filling reactor with no intentional waste of effluent.

Table A2. NITROGEN BALANCE DATA AND PROFILE OF OXIDATION DITCH OPERATION

Nitrogen Input (gm)	Nitrogen Output (gm)	Estimated N- Input (1-2)	Total N in Ditch (gm)	Observed Change of N in Ditch	Loss of N, gm (3-5)	Time Period (days)	N- Loss per day (gm)	Period
3127	0	3127	2975	497	2630	5	526	Initial Filling Period Oct. 19 - Nov. 1, 1972
1876	0	1876	3634	659	1217	3	406	
2502	0	2502	4749	1115	1387	4	347	
625	0	625	4690	-59	684	1	684	
1251	1584	-333	4570	-120	-213	2	-107	Flow-through Period Nov. 1, 1972 - Jan. 9, 1973
2502	2567	-65	2362	-2208	2143	4	536	
1876	1287	589	2215	-147	736	3	245	
2502	1520	982	2186	-29	1011	4	253	
1876	828	1048	2277	91	957	3	319	
4378	2041	2337	2532	255	2082	7	297	
2502	1358	1144	3163	631	513	4	128	
1876	985	891	3003	-160	1051	3	350	
2502	1255	1247	3258	255	992	4	248	
1876	1281	595	3759	501	94	3	31	
2502	1824	678	3673	-86	764	4	191	
4378	3819	559	3290	-383	942	7	134	
1876	1544	332	3168	-122	454	3	151	
4378	3550	828	3134	-34	862	7	123	
2502	1887	615	3242	108	507	4	127	
1876	1512	364	3168	-74	438	3	146	
2502	2010	492	3465	297	195	4	49	

Table A2. NITROGEN BALANCE DATA AND PROFILE OF OXIDATION DITCH OPERATION (continued)

Nitrogen Input (gm)	Nitrogen Output (gm)	Estimated N- Input (1-2)	Total N in Ditch (gm)	Observed Change of N in Ditch	Loss of N, gm (3-5)	Time Period (days)	N- Loss per day (gm)	Period
1876	0	1876	3588	123	1753	3	584	Denitrification period without flow-through operation
1876	0	1876	3624	36	1841	3	614	
2502	0	2502	4247	623	1879	4	470	
1876	0	1876	5049	802	1074	3	358	
2501	0	2501	7313	2264	237	4	59	
1876	0	1876	8545	1232	644	3	215	Second filling period w/o flow-through Jan. 25 - Jan. 30, 1973
5003	5010	-7	5771	-2774	2767	8	346	Second flow-through period Jan. 30 - April 3, 1973
4324	4167	157	6421	651	-494	7	71	
1197	1046	151	6166	-256	407	2	204	
5003	4448	555	5041	-1125	1680	8	210	
2394	1868	527	4648	-394	921	4	230	
1796	1439	357	5178	530	-173	3	-58	
2394	2109	285	5691	513	-228	4	-57	
1796	1585	211	4991	-700	911	3	304	
2394	1736	658	4786	-204	862	4	216	
1796	1239	557	4518	-268	825	3	275	
2394	1743	651	4647	129	522	4	131	
1796	1351	445	4457	-190	635	3	212	
2394	1725	669	4150	-307	976	4	244	
1796	1214	582	3827	-324	906	3	302	
2394	1534	860	3923	97	763	4	191	

Table A2. NITROGEN BALANCE DATA AND PROFILE OF OXIDATION DITCH OPERATION (concluded)

Nitrogen Input (gm)	Nitrogen Output (gm)	Estimated N- Input (1-2)	Total N in Ditch (gm)	Observed Change of N in Ditch	Loss of N, gm (3-5)	Time Period (days)	N- Loss per day (gm)	Period
599	397	202	3804	-119	321	1	321	Second denitrification period April 3 - April 9, 1973
599	386	213	3520	-284	497	1	497	
599	364	235	3225	-295	530	1	530	
599	337	262	3500	275	-13	1	-13	
1197	657	540	3312	-189	738	2	369	
598	314	284	3476	165	119	1	119	

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